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# **THE OUTCOMES OF BILATERAL COCHLEAR IMPLANTS IN ADULT RECIPIENTS**

**BY**

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## LIST OF ABBREVIATIONS

<b>CI</b>	Cochlear implant
<b>CIs</b>	Cochlear implants
<b>BCI</b>	Bilateral cochlear implant
<b>BCIs</b>	Bilateral cochlear implants
<b>PCIP</b>	Pretoria Cochlear Implant Program
<b>S</b>	Subject
<b>SOP</b>	Significant other person
<b>N</b>	Number
<b>QOL</b>	Quality of life
<b>ASHA</b>	American Speech Language and Hearing Association



## ABSTRACT

**NAME:** Tania Swart  
**TITLE:** The outcomes of bilateral cochlear implants in adult recipients  
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**DEPARTMENT:** Communication Pathology  
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Although unilateral cochlear implants generally provide good speech understanding under quiet conditions, patients with unilateral cochlear implants frequently report difficulty in understanding speech in the presence of background noise and difficulty in localizing the source of sound. Since these two listening functions require binaural hearing in normal hearing individuals, there has been a growing interest in bilateral cochlear implants as intervention type for people with severe-to-profound bilateral hearing loss.

This study investigated the outcomes of bilateral cochlear implants in all the adult recipients of the Pretoria Cochlear Implant Program. All the subjects with BCIs were asked to choose a significant other person to participate in the study. All the subjects (i.e. subjects with BCIs and their significant other people) were asked to participate in a semi-structured interview and to fill out a researcher-generated questionnaire. The subjects with BCIs also underwent audiometric testing.

The majority of the subjects with BCIs were found to demonstrate improved ability to understand speech in the presence of background noise and, to some extent, in their ability to localize sound sources. As both quantitative and qualitative methods were used to determine the outcomes, it could be demonstrated that the majority of adult bilateral cochlear implant recipients gain from the auditory benefits in everyday listening situations. The majority of subjects and their significant other people conferred that their improved auditory skills allow them to be more participative in social, cultural, and other activities, which add to the quality of their lives.

*Key words: bilateral cochlear implants, subjects with BCIs, significant other people, quantitative and qualitative measures, quality of life*

## OPSOMMING

<b>NAAM:</b>	Tania Swart
<b>TITEL:</b>	Die uitkomste van bilaterale kogleëre inplantings in volwassenes
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Alhoewel mense met unilaterale kogleëre inplantings oor die algemeen goeie begrip van spraak onder stil luister omstandighede ervaar, word daar gereeld verslag gedoen van probleme om spraak te verstaan in die teenwoordigheid van agtergrondsgeraas en om klanke te lokaliseer. Aangesien hierdie twee luisterfunksies binourale gehoor in mense met normale gehoor vereis, is daar tans 'n groeiende belangstelling in bilaterale kogleëre inplantings (BKIs) as 'n vorm van intervensie vir mense met ernstige tot totale gehoorverlies.

Die huidige studie het die uitkomste van bilaterale kogleëre inplantings in al die volwassenes van die Pretoria Kogleëre Inplantingsprogram ondersoek. Al die deelnemers met BKIs is versoek om 'n belangrike ander persoon te identifiseer om ook aan die studie deel te neem. Al die deelnemers (deelnemers met BKIs en hulle belangrike ander persone) is versoek om aan 'n semi-gestruktureerde onderhoud deel te neem en om 'n vraelys, wat deur die navorser saamgestel is, in te vul. Die deelnemers met BKIs het ook aan oudiometriese toetsing deelgeneem.

Die meerderheid van die deelnemers met BKIs het 'n definitiewe verbetering in hul vermoë om spraak te verstaan in die teenwoordigheid van agtergrondsgeraas, sowel as om die oorsprong van klank te lokaliseer, ervaar. Aangesien daar van kwantitatiewe en kwalitatiewe metodes gebruik gemaak is om die uitkomste te bepaal, kon daar bewys gelewer word dat die meerderheid van die deelnemers met BKIs by die ouditiewe verbeteringe in alledaagse luister-omstandighede baat. Die meerderheid van die deelnemers met BKIs en belangrike ander persone het bevestig dat hul verbeterde ouditiewe vaardighede hulle in staat stel om meer deel

te neem aan sosiale, kulturele en ander aktiwiteite, wat bydra tot hul lewenskwaliteit.

*Sleutelwoorde: Bilateral kogleêre inplantings (BKIs), deelnemers met BKIs, belangrike ander persone, kwantitatiewe en kwalitatiewe metodes, lewenskwaliteit*

## **CHAPTER 1**

### **PERSPECTIVES ON BILATERAL COCHLEAR IMPLANTS IN ADULTS**

The aim of Chapter 1 is not only to outline and set the context in which the research question originated, but also to evaluate recent research and to identify shortcomings as well as possible discrepancies regarding the topic. This allows the researcher to formulate a rationale for conducting the current research study and to compose a legitimate research question. This chapter also includes referenced definitions for the key terminology used, and finally, a layout of the content of each chapter.

#### **1.1 Introduction**

Cochlear implants (CIs) have become the most powerful and dynamic means of providing functional hearing to some individuals with severe-to-profound hearing loss. The modern cochlear implant is the result of decades of world-wide research and development by scientists. An in-depth discussion of the development of CIs is beyond the scope of this study, but the following discussion will guide the reader through the main accomplishments that preceded the latest developments in the field that is the focus of this study: bilateral cochlear implants.

#### **1.2 Rationale**

“Cochlear implants are surgically implanted electronic devices coupled to external components that provide useful hearing and improved communication to both adults and children with severe-to-profound hearing loss” (Katz, 2002:740). Cochlear implants have several components that work together to provide sound to the individual with hearing loss. These components include microphones, external speech processors, signal-transfer-hardware, transmitters, receivers and electrodes. The microphone receives and converts sound in a continuous way into an electrical representation. The speech processor and signal-transfer-hardware modify the electrical signal for the transmitter (placed on the mastoid and usually held in place by magnets) to send the processed signals via radiofrequency to the receiver (surgically placed in a “well” over the mastoid). Once the signal is received, electrical energy is sent to one or many electrodes in the electrode array. The

electrode array, which lies within the cochlea, delivers the electric signal to one of the electrodes along its length. An electric field is next generated and serves to discharge the neural components of the auditory system. Finally, the eighth nerve conveys the stimulus to the central nervous system, which decodes and interprets the signal (Quinn & Ryan, 2003:1).

An Italian physicist, Volta accomplished the earliest external electrical stimulation of the auditory system in 1790. He inserted a metal rod into each ear and then subjected himself to electric jolts of approximately 50 volts. He reported that the sensation was that of receiving a blow to the head followed by the sound of thick soup boiling (Niparko & Lustig, 2003:292). Subsequently, a number of scientists continued to experiment with electricity and hearing. Djourno and Eyries (1957, in Katz, 2002:740) provided the first published report of electrical stimulation of the auditory system in a deaf individual. Initial successes with a permanent implant in the patient's temporalis muscle lead them to place a second coil against the overlying skin. This implant consisted of an active lead placed on the auditory nerve through an opening in the vestibule, an induction coil and an indifferent electrode. Although the patient was not able to discriminate the sounds of speech, a definite increase in sound awareness and improved speech reading skills were reported (Katz, 2002:740).

Development continued steadily and during the early 1960s, Dr. William House implanted several devices in totally deaf volunteer patients in the USA. Although these early CIs were at first physiologically rejected due to a lack of biocompatibility of the insulating material, there was optimism that they might provide a solution for people with sensory neural deafness (House, 2003:2). Following the first attempt, Dr. House and Jack Urban, an innovative engineer, set out to make CIs a clinical reality. Together they built the first wearable single electrode signal processor that provided the patient with the sensation of sound (House, 2003:5). House and Urban continued to research multiple electrodes in search for an ideal solution.

The breakthrough was achieved in August 1978 in Australia when Professor Graeme Clark implanted the first fully implantable, multiple-channel cochlear implant into an adult (Waltzman & Cohen, 2000:69). In 1985 the US Food and Drug Administration (FDA) approved the multiple-channel cochlear implant as safe and

effective for providing understanding of connected speech to profoundly deaf adults who had had hearing before becoming deaf (Waltzman & Cohen, 2000:69). This multiple-channel cochlear implant and speech processing strategy was the first to give profoundly deaf people the ability to understand open-set speech both with assistance from lip-reading and with electrical stimulation alone (Clark, 2003:23; Clark, 2006:791). Large scale clinical trials in the 1990s concluded that the performance of postlingual deafened adults with a multiple-channel cochlear implant was better than the performance of post-lingual deafened adults with a single channel device. Since that time, a great deal of research has been dedicated to improving the design of the implant system, identifying the best intra-cochlear array and stimulation mode, refining the processing strategies available, and miniaturizing both the external and internal hardware.

Currently the top three cochlear implant devices are manufactured by Cochlear Limited, Australia; MED-EL, Austria; and Advanced Bionics in the United States. According to a technical report by ASHA (2004:2), the three FDA approved cochlear implant systems available today in the United States and other countries are the Clarion, Nucleus and MED-EL. As each manufacturer adapts some of the successful innovations of the other companies' products to their own devices, the Nucleus, Clarion, and MED-EL cochlear implant systems share several features. All three cochlear implant systems provide multiple channel stimulation. A second similarity is that all three major cochlear implant systems use transdermal communication between the externally worn hardware and the implanted electronic components. Another similarity is that all three cochlear implant systems incorporate technology known as telemetry that can be used to monitor the integrity of the intra-cochlear electrodes after they have been implanted. Fourthly, all three cochlear implant systems offer a range of different speech processing options and the general process used to program the speech processor for all three cochlear implant devices is fairly similar (ASHA, 2004:3).

Programming the speech processor of the cochlear implant typically requires establishing a threshold and a comfortable (C) level, that is, a maximum stimulation level, for each of the individual intra-cochlear electrodes. These C-levels are customized for each individual user and need to be adjusted several times for most

individuals during the first year, but less frequently thereafter. To date the most popular speech processing strategies are the 'Continuous Interleaved Sampling' (CIS), 'Spectral Peak' (SPEAK) and 'Advanced Combination Encoder' (ACE). The enhanced speech processing and pre-processing algorithms and the flexibility of the various speech processing algorithms available to each individual add to the increasing success of many adult cochlear implant recipients' speech perception abilities (Wiegman, personal communication, 2007). Although both CIS and SPEAK have good processing qualities, ACE is considered to be superior as it is able to convey the different pitches in speech, at rapid changes in loudness. In short, ACE combines the benefits of both CIS and SPEAK.

Unlike in the case of the speech processing strategy where ACE is considered the more advanced option, there is no clear-cut consensus that any particular cochlear implant device is more superior to the other devices. Interestingly, researchers have found that the overall performance with a cochlear implant may vary tremendously, even among users of the same device (ASHA, 2004:4). With all three devices (i.e. the Clarion, Nucleus and MED-EL), some recipients attain very high levels of performance in the 'sound only' mode while others receive only minimal benefit and attain little more than environmental awareness and speech reading enhancement. Since cochlear implant devices have many similarities, other criteria are often considered when choosing a cochlear implant device. The criteria for choosing a cochlear implant device usually include: the usability of external components; cosmetic factors; battery life; reliability of the internal and external components; customer service from the manufacturer; the familiarity of the user's surgeon and audiologist with the particular device; and other factors such as anatomical concerns. The cost of cochlear implant devices does not vary significantly among the different manufacturers (ASHA, 2004:3).

Over and above the mentioned criteria considered when choosing a cochlear implant device, each cochlear implant program implements its own criteria in selecting the program's candidates. The selection criteria not only ensure that higher rates of successful outcomes are achieved but also increase the likelihood that all expectations are met. Two distinctive groups of people with hearing loss are prelingually deaf *children* and postlingually deaf *adults*. Each group has different



expectations, needs and outcomes with CIs. The outcomes of late implanted prelingually deafened adults are generally expected to be less than those of cochlear implant users who have had a shorter term of deafness, as in the case of postlingually deafened adults (Waltzman, Roland & Cohen, 2002:334). Interestingly, despite the differences in performance and expectations, people from both groups (i.e. prelingually and postlingually deafened adults) have been selected to receive CIs. According to three cochlear implant manufacturers (Cochlear Limited, MED-EL and Advanced Bionics), the current selection criteria for *adults* to obtain a cochlear implant generally include the following:

- Bilateral severe-to-profound or moderate-to-profound hearing loss;
- Pre- or postlinguistic hearing loss with oral / aural communication skills;
- Restricted or no useful benefit from hearing aids;
- Fifty percent or less open-set sentence discrimination;
- A desire to be part of the hearing world;
- A medically sound person with a surgically implantable cochlea.

It is generally accepted that in the case of bilateral cochlear implantation the same selection criteria are used when a person applies for a second cochlear implant as for the first cochlear implant. Each ear is viewed independently and criteria such as the applicant's physical condition that could preclude general anesthetic and whether the cochlea is surgically implantable, degree of the ear-specific hearing loss, and success with the first cochlear implant as well as with bimodal amplification, are particularly important. Another criterion that carries great weight is the worth that the second cochlear implant is expected to append towards the recipients' quality of life and psychosocial functioning.

The influential World Health Organization Quality of Life (WHOQOL) group defines quality of life as: "An individual's perspective of their position in life in the context of their culture and value systems in which they live and in relation to their goals, expectations, values and concerns incorporating physical health, psychological state, level of independence, social relations, personal beliefs and their relationship to salient features of the environment... quality of life refers to the subjective evaluation which is embedded in a cultural, social and environmental context" (WHOQOL, 1995 in Phillips, 2006:33). According to Bowling (1997), there is no

consensus regarding a definition of quality of life (QOL). Early work in the field focused on client ill-health with key terms such as morbidity, mortality, and service utilization. More recently the concept of health has been widened to include social and psychological as well as physical aspects, so that terms such as functional ability, social health and positive health have become important. The other main development in measuring QOL has been the shift from physicians' and caregivers' perceptions of QOL to the individual's subjective feelings of their own health or well-being. It is the current researcher's opinion that QOL in general involves the physical, emotional, intellectual, and cultural satisfaction derived from a person's everyday life. In addition, literature has indicated significant correlations between improved QOL and improved communication after cochlear implantation (Fitzpatrick & Schramm, 2006:192). It is therefore considered a realistic expectation that positive objective outcomes with regard to the recipient's auditory receptive skills may develop into a cascade of benefits including subjective outcomes related to QOL.

Since the inception of cochlear implant research it has been suggested that psychological factors provide an important key to the cochlear implant recipient's success and that the investigation thereof should be included in research programs (Cary, Berliner, Wexler & Miller, 1982 in Knutson, Johnson & Murray, 2006:280). Knutson et al. (2006:290) sought to determine whether persons seeking CIs during the time of their research differed psychologically from those referred in the early 1980's. Their results indicated that reduced psychological distress and increased social interaction in pleasant activities continue to be suitable goals of cochlear implantation. Thus, improved psychosocial status continues to be a suitable outcome measure for evaluating cochlear implantation and other forms of rehabilitation. The past few decades has seen dynamic development in the field of cochlear implantation and its effect on other human domains such as QOL. The number of cochlear implant recipients has steadily increased to approximately 100,000 recipients worldwide (Summerfield, Barton, Toner, McAllen, Proops, Harries, Cooper, Court, Gray, Osborne, Doran, Ramsden, Mawmen, O'driscoll, Graham, Alesky, Meerton, Verschuur, Ashcroft & Pringle, 2006:99).

In the mid 1990's, after unilateral cochlear implantation had been proven an effective method in treating severe-to-profound deafness, investigators theorized that bilateral cochlear implantation would be even more effective. This assumption was based on two aspects: known deficits experienced by both unilateral cochlear implant users and individuals with unilateral profound hearing loss, and knowledge about phenomena that make binaural hearing possible (Peters, 2006:2). At present, approximately 3,000 recipients have bilateral cochlear implants (Peters, 2006:1). Although only a small percentage (3%) of cochlear implant recipients worldwide have bilateral cochlear implants (BCIs), it has become a growing trend globally. One of the leading cochlear implant device manufacturers, The Cochlear Americas, reported that 15% of their 2006 sales in the USA were for BCIs (retrieved from a report on cochlear implants on the Wikipedia Encyclopedia website, accessed May 27, 2007).

It was previously unknown whether bilateral electrical stimulation could be integrated by the central nervous system. At present it is accepted that the brain can integrate electrical stimulation from two ears. The perception therefore is that BCIs, as intervention type for severe-to-profound hearing loss, best simulate binaural hearing (Tyler, Dunn, Witt & Preece, 2003:392). Binaural hearing allows normal hearing individuals to understand speech in noisy situations, to localize sound sources, and to facilitate listening in conversations from either side with equal clarity (Dunn, Tyler & Witt, 2005:668). According to Müller, Schön and Helms (2001, in Perold, 2006:7), the human auditory system is able to achieve binaural hearing through noise reduction and acoustical orientation abilities that depend on the subject having access to time, level, and spectral differences between the two sound signals sensed by the two ears. The latter abilities are scientifically accredited to the following three effects:

- The *Head Shadow effect*: When listening to speech in noise, the head acts as a sound barrier that attenuates noise on the side away from the speech. Therefore, when one ear is close to the noise source, adding the other ear (away from the noise) provides a second receptor where the speech is louder than the competing noise. The brain can automatically switch to the ear with the

better signal-to-noise ratio to take advantage of the greater clarity (Tyler et al., 2003:389).

- The *Binaural squelch effect*: When the signal and the noise come from different directions, the brain separates them by comparing time, intensity, and pitch differences between the two ears. The practical effect is that the brain can suppress signals that the listener does not wish to hear. For example, in a room with many competing voices, the brain can choose to focus on and listen to one speaker among many (Wilson, Lawson, Müller, Tyler & Kiefer, 2003:230).
- The *Binaural summation or the redundancy effect*: When a person listens with two ears, redundant information from each ear is processed in the brain and the threshold of hearing improves significantly. Sound that is heard binaurally rather than monaurally is perceived to be twice as loud, and the sensitivity to small differences in intensity and frequency increases. Although the binaural summation effect contributes to a person's speech perception in both quiet and noisy conditions, benefits from the head shadow effect are more prominent in BCI users (Tyler et al., 2003:389).

Studies indicate that most CI recipients show improvements in head shadow effects and in localizing sound with two implants (Tyler et al., 2003:392; Peters, 2006:1; Brown & Balkany, 2007:315). A smaller number of bilateral implant users also show binaural summation and binaural squelch effects (Müller, Schön & Helms, 2002:201; Litovsky, Parkinson, Arcaroli, Peters, Lake, Johnstone & Gongqiang, 2004:654). Ultimately, substantial advancements in these three effects contribute to the BCI recipient's ability to participate with more ease in everyday listening tasks that require binaural hearing.

Due to the rapid progress in advancements in the field of CIs today, more high-tech devices are commercially available. Consequently, binaural auditory benefits are a realistic outcome for BCI users with probable advantages in QOL. It is important, however, that these advancements be monitored. As with any commercial production, costs increase with increase in eminence. The improvements that accrued with the development of CIs in general, add to the prohibitive cost of the device. Consequently, cost implications may preclude the implantation of future cochlear implant devices with improved technology (retrieved from Cochlear

Limited's website, accessed May 25, 2007). This gives rise to another matter of great significance within the field of BCIs and QOL: the issue of cost effectiveness.

International studies investigating the cost effectiveness of BCIs have produced several interesting findings. Summerfield et al. (2002, in Summerfield et al., 2006:100) conducted a cost utility scenario analysis of BCIs, and found that more QOL is likely to be gained per unit of expenditure on unilateral implants than bilateral implants. Summerfield et al. (2006:99) used a multivariate analysis to illustrate that positive changes in QOL of bilateral cochlear implant recipients are solely associated with improvements in hearing. Their findings show self-reported improved abilities in spatial hearing, quality of hearing, and in understanding of speech. Some improvements in hearing were offset by negative changes associated with tinnitus but even in the best-case scenario, in which no worsening of tinnitus was assumed to occur, the gain in QOL was too small to achieve an acceptable cost effectiveness ratio.

According to an article retrieved from Cochlear Limited (2005, accessed May 25, 2007), it is possible that simultaneous bilateral implantation will be more cost effective than sequential implantation, due to the reduced surgical and programming costs. Considering the immense costs involved in cochlear implantation, any possible saving in cost should especially be investigated in developing and socio-economically diverse countries where financial and human resources are limited. According to the World Health Organization (WHO, 2001), an estimated 250 million people worldwide representing approximately 4% of the world's total population, have some form of hearing loss. Two thirds of the population of people with hearing impairment (i.e. 165 million people) live in developing countries and can-not afford the basic price of a hearing aid (HA). Basic process of hearing aids (HAs) in developing countries start at approximately ZAR 2000,00 (South African rand) (Sooful, 2007:29). In 2001, the WHO collaborated with several hearing aid companies to reduce their costs and find ways to supply hearing aids to people with hearing loss in developing countries by 2004. Predictably, the people with hearing loss in developing countries experienced severe difficulties with the maintenance of the hearing aids and the cost of a standard pack of six zinc air batteries which was too expensive for the average HA

user to purchase (Sooful, 2007:29). Although hearing aids were used for the purpose of that study, the difficulties with the maintenance of hearing aids emphasizes the potential difficulties of sustaining the immense costs involved in the maintenance of CIs. According to Cochlear Limited (2005, accessed January 3, 2009), some cochlear implant systems rely on brand specific rechargeable batteries that may last only a few hours while other systems can operate up to five days on one set (three batteries) of commercially available batteries. Considering that BCI recipients have two cochlear implants to maintain, merely having to sustain the power supply can be a financial burden for some. Variations in noise levels, skin thickness and mapping strategies all affect potential battery life.

The issue of cost effectiveness in relation to QOL after receipt of a *second* cochlear implant is inescapably one that demands attention especially in developing countries such as South Africa. Research has shown that individuals can, in some situations, combine and use acoustic stimuli from one ear and electrical stimulation from the other ear to obtain bilateral hearing effects, including enhanced speech perception in noise and localization abilities (Firszt, Reeder & Skinner, 2008:755 and Ching, Psarros, Hill, Dilon & Incerti, 2001 in Dunn et al., 2005:669). A more recent paper by Ching, Massie, Wanrooy, Rushbrooke and Psarros (2009:25) evaluated the benefits of bimodal fittings (combining a hearing aid and a cochlear implant in the opposite ear) or bilateral cochlear implantation, relative to unilateral implantation, for children. On average, the size of binaural speech intelligibility advantages due to redundancy and head shadow was similar for the two bilateral conditions. An added advantage of bimodal fitting was that the low-frequency cues provided by acoustic hearing complemented the high-frequency cues conveyed by electric hearing in perception of voice and music. Some children with bilateral cochlear implants were able to use spatial separation between speech and noise to improve speech perception in noise. This was thought a combined effect of the directional microphones in their implant systems and their ability to use spatial cues (Ching et al., 2009:26).

According to Perold (2006:16) and Dunn et al. (2005:669) wearing a HA on the non-implanted ear also helps to improve the patient's QOL. It eliminates the negative effects of auditory deprivation in the non-implanted ear, enhances the

likelihood of masking tinnitus in both ears, provides enhanced quality of sound, ensures better speech perception in noise, and additionally one device is usually available when the other is not. Some other positive findings relate to binaural benefits in speech, localization abilities and improved functional performance when using bimodal hearing devices (Firszt et al., 2008:749 and Ching, Incerti & Hill, 2004 in Perold, 2006:37). Individuals who consider undertaking the additional risks and costs of obtaining a second cochlear implant need to be informed of all the options available and need more than audiometric data to help in the decision making process.

Botha (2003:11) recommends bimodal amplification rather than binaural BCIs as the most suitable option within the South African context. Her recommendation is not only based on research that has proven binaural advantages in bimodal amplification, but also on the following revised implications of providing BCIs:

- The time and trained personnel needed for mapping can be limited;
- The costs in maintaining two devices can be excessive;
- Insurance companies doubt whether the benefits of two CIs are worth the costs and risks, and this prevents them from covering the second implant;
- Differences in interaural timing, interaural intensity and different speech processors can create difficulties in coordinating the two devices - again trained personnel for auditory training are required;
- The wide variation that exists in performance across individuals makes it difficult to assure a positive outcome using two devices.

It is important to note that some bimodal users (CI together with HA) only move towards BCIs as soon as benefit is no longer obtained from the HA or when severe recruitment makes the use of the HA unbearable. On the other hand, some researchers find that an increasing number of patients have enough residual hearing in the non-implanted ear to wear a HA, but since the criteria for cochlear implant candidacy has become more liberal, patients with more residual hearing are now being implanted (Gelfand, Silman & Ross, 1987 in Dunn et al., 2005:669). Litovsky, Johnstone and Parkinson (2006:78) state that BCIs are being provided in an attempt to increase people's QOL and possibly improve listening in daily realistic listening situations. This clinical approach is primarily rooted in the assumption that,

since people with normal hearing rely on two ears for the binaural benefits mentioned earlier, deaf individuals may also benefit from binaural hearing and should also have two 'good' ears in order to maximize their performances (Litovsky et al., 2006:78). Although the benefits that individuals with normal hearing achieve from binaural hearing has been established without doubt, many factors are involved when striving to obtain these benefits by procuring two "bionic ears" (i.e. cochlear implants). Although bilateral cochlear implantation may provide a recipient with a range of potential benefits, the process involves intense decision-making, irreversible surgery and highly demanding intervention, twice. This is evident in the remark by a caregiver of a bilateral cochlear implant recipient: "...to go through another operation, see all those bandages, it's terribly scary, and the length of the operation as well..." (Gautschi, 2003:61).

BCIs as successful treatment option need to be corroborated and motivated for, based on the efficiency of the cochlear implant program. Research within each country's cochlear implant center/s is therefore imperative not only to review and validate that program's selection criteria but also to substantiate candidacy and treatment efficacy. Chester-Brown (2005, in Jessop, 2005:8) emphasizes that each cochlear implant program's selection criteria ultimately dictate the profile of that program's clients. This becomes evident from careful inspection of the outcomes that provide an accurate data base of the clients in each program. In order to validate a selection criterion, the outcomes of every cochlear implant recipient should be carefully scrutinized to ensure that patients are aware of the potential risks and have realistic expectations of the possible benefits, and that these expectations are largely met.

The expectations and perceptions of adults who consider BCIs may include some of the uncertainties that were documented by a young adult and BCI candidate during his decision making process (retrieved from the 'Healthy Hearing' website, accessed May 22, 2007). He experienced mixed emotions as to how it would feel to have two different sounds entering the brain simultaneously. There was uncertainty regarding the different cochlear implant devices, the one being technologically more advanced than the other, and having a body worn processor versus a behind the ear processor. He was uncertain whether his hearing would be perceptibly



better on one side than the other and had his doubts whether more speech would be understood without speechreading. The candidate speculated whether listening to music could become more enjoyable than it already was with one CI and he questioned whether the second CI would be worth just as much as the first time when there was nothing to lose. Lastly the young adult questioned the immediate need for a second cochlear implant knowing that science continues to make excellent progress with CIs and that postponing another five or 10 years might result in obtaining a more powerful and smaller cochlear implant.

It is clear that even today, in the modern world where evidence-based practise is the standard, potential candidates still experience doubts and fears. One can only imagine the doubts that must have been adjunct to the innovation almost 30 years ago, when CIs were first introduced. Evidently, the more knowledge implanters have gained about CIs and its successes over the last few years, the more relaxed the selection criteria of the different cochlear implant programs have become. This is apparent when one recalls that in December 1984, CIs were initially approved by the FDA only for postlingually deafened adults who experienced no improvement in hearing with high-powered hearing aids. In 1990, the FDA lowered the approved age for implantation to two years, then 18 months in 1998, and finally 12 months in 2002 with special approval considered for babies as young as six months in the United States. Today the world's youngest cochlear implant recipient is little Marie-Josephine who, at the age of five months, received bilateral cochlear implants in a simultaneous surgical procedure at the Freiburg University ENT-clinic in Germany on January 5<sup>th</sup>, 2004 (Aschendorff, Klenzner & Laszig, 2003:995).

It is interesting, yet not surprising, to note that the majority of innovations emanated from the first world countries such as Australia, the United States, and Germany. However, even in the leading countries the variability in performance remains quite high, with limited explanations as to the reasons for good and poor outcomes (Moller, 2006:50). Following the international trends, the annual growth in cochlear implantation in South Africa is evidence of the rapid development in the field of Audiology in this country. The investigation of the outcomes of BCIs is thus of utmost importance to not only determine the contribution of bilateral implants to the field of hearing enhancement in South Africa, but also to examine each bilateral

cochlear implant recipient's performance which ultimately reflects a cochlear implant program's efficiency and success. Although the manufacturer's components of a cochlear implant device are important in ensuring positive outcomes, equally significant is the individual's ability to adjust to, interpret, and respond to the binaural electric stimulus in everyday situations (Quinn et al., 2003:2). The length of time spent without sound stimulation of the auditory nerve, presence or absence of previous experience with sound, personal motivation, community or family support, and opportunities for rehabilitation have also been shown to be important factors in achieving good outcomes. These factors are likely to be instrumental in explaining significant differences in patient outcomes despite similar preoperative auditory deficits, surgical procedures, and cochlear implant hardware (Quinn et al., 2003:2). Audiometric evaluation alone is thus not sufficient in measuring the outcomes of BCIs. The recipient needs to perceive the benefits of the BCIs in daily living and listening situations.

### **1.3 Problem statement**

The number of BCI recipients is steadily increasing as service providers attempt to provide better hearing to people with severe-to-profound hearing loss. Although international research centers have investigated and are currently evaluating the benefits to and outcomes of their clients, BCIs have not yet been approved as standard practice. The current researcher is of the opinion that the outcomes of this highly specialized and technologically advanced intervention remain unique to each individual. This individualism may be ascribed to each unique candidate and her / his history of hearing loss, the selection criteria used by the different independent cochlear implant programs, and ultimately each country's medical policy and financial contributory act. Investigating both the objective and subjective outcomes of adults with BCIs may provide information that can assist future candidates to better understand the differences in performances and may help to create realistic expectations for both the candidate and the CI program. An in-depth investigation of both the objective and subjective outcomes of BCIs is essential. This will allow the monaural cochlear implant user to consider the advantages and weigh the possible risks and the uncertainties of BCIs against her / his current performance

with unilateral implantation. This study aimed to answer the following research question: “What are the outcomes of BCIs in adults?”

#### **1.4 Definitions of key terminology used in this study**

- **Adult:** An adult is an individual 18 years and older. According to the South African Child Care Act 74 of 1983 a person over the age of 14 years may independently consent to any medical treatment of himself and, once he reaches the age of 18 years, a person may independently consent to the performance of any operation on him/herself. No upper age limit has been set for cochlear implants (Child Care Act 74 of 1983).
- **Child:** In this study a child is an individual up to and including the age of 17 years (Child Care Act 74 of 1983).
- **Outcomes:** Although this study did not include a comparison between the subjects with BCIs’ auditory performance prior to receipt of the second cochlear implant and after receipt of the second cochlear implant, the term ‘outcomes’ refers to the subject with BCIs’ current performance with BCIs as measured objectively and reported subjectively.
- **Auditory deprivation:** The diminution or absence of sensory activity in neural structures central to the end-organ of hearing, due to a reduction in auditory stimulation resulting from hearing loss (Stach, 2003:30).
- **Open-set speech discrimination:** The ability to understand speech without visual cues such as those provided by speechreading.
- **Qualitative** and **quantitative** versus **objective** and **subjective:** Throughout this study the terms ‘quantitative’ and ‘qualitative’ are generally used when referred to the approaches, methods or materials used to collect, analyze, and interpret the data. The terms ‘objective’ and ‘subjective’ are generally used to differentiate the outcomes viz. objective auditory outcomes from subjective outcomes as perceived by the subjects with BCIs and reported by their significant other person.

## **1.5 Conclusion to Chapter one**

The information put forward in this chapter leads to the conclusion that bilateral cochlear implantation has become a viable and increasingly preferred treatment option for people with severe-to-profound hearing loss. In this study the focus is on the adult population, which includes people who were either pre- or postlingually deafened. Due to the wide range of potential candidates for CIs in general and the different expectations and needs the candidates may have, the outcomes of this relatively novel intervention remain dependent on each bilateral cochlear implant recipient. The various factors including invasive surgery, excessive costs, and irresolute outcomes, demand investigation to establish the validity of the treatment options within each cochlear implant program.

## **1.6 Summary of Chapters**

The aim of Chapter 1 is not only to outline and set the context in which the problem originated, but also to evaluate recent research, and to identify shortcomings and probable discrepancies on the topic. This allows the researcher to formulate a rationale for conducting the current research and to formulate a legitimate research question. This chapter also includes referenced definitions of the key terminology used and finally a summary of the content of each chapter in table form.

Chapter 2 constitutes the theoretical component of this study. This chapter critically reviews recent research on the topic and discusses relevant concepts based on controlled observations. For this purpose, the chapter commences with an introduction to bilateral cochlear implants, followed by a discussion of the reputed benefits, some negative commentary, and ultimately the assessment of the benefits using both objective and subjective measurements. This enables the reader to differentiate and become accustomed with all the potential outcomes of BCIs.

Chapter 3 describes the research method in detail. Each section in the research method is thoroughly explained and its inclusion is justified. The different sections include the research aims, design, a description of the sample and the material and apparatus used for data collection. Data recording and data analysis procedures are also described. Throughout this chapter ethical issues are considered and the

research method is presented in such a way that any reader or potential researcher will be able to duplicate the execution of this study.

In Chapter 4, the collected and analyzed data (i.e. the results) are discussed in detail. The results are presented according to the sub-aims of this study and where appropriate, the results are displayed visually using graphic forms including tables and figures. Significant findings are clearly illustrated and supported by an interpretation of that specific finding.

The conclusions from the results of each sub-aim are provided in Chapter 5. The implications of the findings for the field of Audiology are discussed and recommendations for future research, some of which derived from a critical evaluation of this research project, are made.

## **1.7 Summary**

Chapter 1 outlines and contextualizes the problem and the rationale for conducting the current research. This chapter also introduces some of the main terminology used throughout the study and provides referenced definitions where appropriate. Finally a summary of the content of each chapter is presented.

## **CHAPTER 2**

### **THE POTENTIAL OUTCOMES OF BILATERAL COCHLEAR IMPLANTS IN ADULTS**

Chapter 2 constitutes the theoretical component of this study. The chapter presents a critical review of recent research on the topic and a discussion of controlled observations of various relevant aspects. For this purpose, the chapter commences with an introduction to bilateral cochlear implants (BCIs), followed by a discussion of the potential benefits, some contraindications, and the assessment of the benefits using both objective and subjective measurements.

#### **2.1 An introduction to bilateral cochlear implants**

A unilateral cochlear implant has been approved as a standard part of intervention for severe-to-profound hearing loss and is a common procedure today with few complications. According to Sutton (2004:20), the long term benefits of unilateral implants include definite improvements in sound perception and, with training, cochlear implant users can learn to distinguish speech from environmental sounds. For some, the cochlear implant may help improve their speech, language, and speechreading ability, and contribute to a feeling of increased self-confidence. Nonetheless, the quest for binaural hearing, which is the condition that allows normal hearing listeners to understand speech in everyday listening conditions and to perform spatial hearing tasks, is ongoing (Litovsky, Parkinson, Arcaroli, Peters, Lake, Johnstone & Yu, 2004:648). In normal hearing listeners, binaural hearing depends on the cues of inter-aural amplitude differences (IADs), i.e. differences between the ears in intensity of sounds, and inter-aural timing differences (ITDs), i.e. differences in arrival time between the two ears (Rubinstein, 2004:446). These binaural cues provide the listener with robust information about the direction of sound sources and provide powerful 'tools' for listening in complex environments (Litovsky et al., 2004:653). The 'cocktail party effect' is an example of a difficult listening situation where binaural hearing is crucial for listeners to be able to focus on the speaker and to simultaneously reduce the impact of background noise (Hawley, Litovsky & Culling, 2003:833). Difficulty in the perceptually segregating a single target voice from a competing milieu has been termed 'the cocktail-party problem' (Cherry, 1953, in Hawley et al., 2003:833). The cocktail party problem is

said to be one of the main problems for which a second cochlear implant is seen as a potential solution (retrieved from Cochlear, 2005, accessed September 30, 2007).

According to Cochlear Limited's online bilateral information center (accessed April 12, 2008), most studies on BCIs in both children and adults find that the addition of a second cochlear implant contributes significantly to bilateral listening outcomes. In fact, some of the main findings with BCIs reported to date involve improvement of listening skills in difficult listening situations such as the cocktail party effect. These improvements include an increased ability to focus on a single speaker when surrounded by background noise and an increased ability to identify the location of speech and other important sounds. These findings were most recently reported by Firszt et al. (2008:751), Welsh, Rosen, Welsh and Dragonette, (2004, in Peters, 2006:2) and Brown and Balkany (2007:318).

Unfortunately, these accomplishments may not be a realistic outcome for all bilateral cochlear implant recipients. Müller, Schön and Helms (2001, in Perold, 2006:7) state that noise reduction and acoustical orientation abilities are crucially dependant on the subject having access to time, level, and spectral differences between the two sound signals sensed by the two ears. Research indicates that the performance of adult bilateral cochlear implant users depend on whether or not the bilateral cochlear implant recipient had exposure to binaural stimulation early in life (Litovsky, Johnstone & Parkinson, 2006:78). Litovsky, Agrawal, Jones, Henry and van Hoesel (2005, in Litovsky et al., 2006:79) found that adults who had binaural experience prior to the loss of their hearing had better sensitivity to ITDs than adults who were deprived of hearing in early childhood, or had a congenital hearing loss.

Despite some bilaterally implanted subjects' ability to discriminate ITDs, Smith and Delgutte (2007) and Grantham, Ashmead, Ricketts, Haynes, and Labadie, (2008:44) call attention to their performance, which is typically poorer than that of normal hearing listeners. Grantham et al. (2008:44) conducted a study to measure thresholds for interaural time differences and interaural level differences for acoustically presented noise signals in adults with bilateral cochlear implants. The authors concluded that the subjects with BCIs' (using the CIS+ processing strategy) ability to localize noise signals in the horizontal plane was mediated entirely by ILD

cues and that ITD cues play little or no role. In search of a possible explanation for BCI user's inferior ability to discriminate ITDs, Smith et al. (2007) developed an animal model of bilateral cochlear implantation to study ITDs using trains of electric current pulses delivered via bilaterally implanted intra-cochlear electrodes. They found the sharpness and shape of ITD tuning to depend strongly on stimulus intensity, and concluded that lack of neural plasticity, resulting from previous deafness and deprivation of binaural experience, may play a role in prelingually deafened BCI users' inferior ability to discriminate ITDs with current BCIs.

Some researchers are of the opinion that a bilateral cochlear implant recipient's capacity to utilize binaural effects will ultimately determine the degree of additional benefit which a second cochlear implant will provide to a recipient's auditory aptitude (Brown et al., 2007:316). Research has shown that the auditory benefits of BCIs in adults arise from a combination of three binaural effects, namely, the head shadow-, squelch-, and summation effects. Although studies have shown that all three effects of binaural auditory processing can occur in bilateral cochlear implant subjects (Müller, Schön & Helms, 2002:205), most studies find the reduction of the head shadow effect to be the most consistent and beneficial binaural mechanism (Peters, 2006:3; Tyler, Dunn, Witt & Preece, 2003:392). The head shadow effect is a purely physical phenomenon that is the result of the head acting as an acoustic barrier to sounds and noise coming from different locations in space (Brown et al., 2007:315). Evidently, sounds originating from a source closer to one ear will reach that ear sooner than the other ear and because of the shadowing effect of the head, the sound will be louder on the closer side. These time and level differences provide binaural cues which enable the listener to localize sounds and understand speech in noisy environments (Tyler et al., 2003:389). Unlike the head shadow effect, the squelch and summation effects require the development of advanced auditory processing skills. This allows for the signal from the two ears to be integrated so that an enhanced signal is received by the auditory cortex (Zurec, 1993 in Brown et al., 2007:315).

Overall, bilateral cochlear implantation seeks to improve hearing by taking advantage of these binaural effects and of the central auditory system's capacity to process the binaural cues. In theory the benefits of bilateral cochlear implantation



are more likely to be manifested in postlingually deafened persons than in prelingually deafened persons (Syka, 2002:626). As a group, adult recipients of a cochlear implant who experienced a prelingual onset of severe-to-profound hearing loss, appear to have limited ability to benefit from the squelch and summation effects and have more 'uncertain' benefits from a cochlear implant than their postlingually deafened peers (Peters, 2006:4). Prelingually deafened adults' inability to capitalize on the central auditory processing skills, may be caused by absence of the neural patterns that are usually laid down in the early years of life. In some cases of prelingual onset of deafness, the provision of a cochlear implant (or two) in early childhood or infancy may exceed the expectations set for late implanted prelingually deafened recipients, as early intervention takes advantage of the plasticity of the young brain. Adults who have had a shorter term of deafness often find BCIs particularly useful because of their ability to perform auditory closure or 'fill in certain gaps' from memory. Unlike postlingually deafened individuals, late implanted pre-lingually deafened individuals are unable to draw from past linguistic experiences to assist in communication breakdowns. According to Wooi-Teoh, Pisoni and Miyamoto (2004:1537), prelingually deafened adults with CIs reach their plateau of improvement within six months to a year after implantation; in contrast, postlingually deafened cochlear implant users show continuing improvement in auditory skills three to five years after implantation. It is evident that the sooner after the inception of hearing loss a person receives an implant, the greater the likelihood of benefit (Waltzman, Roland & Cohen, 2002:383).

Binaural experience prior to receipt of the second cochlear implant is not the only important element in a recipient's performance; the extent of bilateral listening experience after implantation is also significant. Litovsky et al. (2004) measured the benefit of BCIs in adults and in children with regard to sound localization and speech intelligibility in noise. The findings of their study suggest that for adults, bilateral hearing leads to improved performance on localization tasks and speech tasks, but it is difficult to ascertain the extent of the advantage after only three months of bilateral listening experience. The conclusion from the study is that BCIs may offer advantages only to some listeners, and that these advantages are highly dependent on bilateral listening experience (Litovsky et al., 2004). Gouws

(2005:25) conducted a similar study on two bilateral cochlear implant recipients and explained that some unexpected findings in her study may be the result of the subjects' brief experience with BCIs. Both subjects in Gouws's (2005) study performed better on the speech discrimination test in quiet when using their 'preferred' unilateral cochlear implant alone, than when using BCIs. On the other hand, both subjects performed better on the speech discrimination test in noise when using their BCIs than with a unilateral cochlear implant alone. Both Gouws (2005) and Litovsky et al. (2004) recommend a more prolonged period of adjustment and learning with BCIs before assessment in future research.

Bilateral listening experience with BCIs appears to be an important yet contentious predictor of a BCI-user's performance on bilateral tasks. Worldwide, several studies have been conducted in an attempt to monitor individual progress at different time intervals post secondary implantation. In the UK, a sequential bilateral study (Cochlear Limited, 2005, accessed February 14, 2007) was conducted to compare bilateral scores with scores using a single implant in the first ear. This study found that significant improvement in binaural tasks (i.e. speech discrimination of sentences in noise) could only be expected nine months after the second cochlear implant. However small but significant improvements in scores were found within the first three months after receiving the second implant for the second ear alone and in the bilateral condition. In German centers, significant bilateral advantages in the speech discrimination of sentences in noise test were found six months after bilateral implantation (Cochlear Limited, 2005, accessed February 14, 2007). Although Litovsky et al. (2004:648) at first stated that the extent of the full advantage of BCIs in adults is difficult to ascertain within the first three months after the second implantation, they consequently reported (Litovsky, 2006 in Brown et al. 2007:317) that for postlingually deafened adults, proficiency in localizing sounds may be a realistic outcome within the first three months after receiving the second implant. Tyler, Gantz and Rubinstein (2002) also found significant benefits in speech discrimination within the first three months after the second implant and moreover, Müller, Schon and Helms (2002) observed benefits in speech discrimination only two months after the activation of the second cochlear implant.

It is clear that after a certain extent of bilateral listening experience, BCIs can, in some cases, utilize the binaural processing of the auditory system and increase performance over a monaural implant. However, BCIs have not yet been approved as standard practice and intensive research is still called for. This could be due to the aspects that are yet to be clarified, including the differences among users of BCIs; the users' ability or inability to capitalize on the opportunity allowed for binaural effects by BCIs; questions concerning cost-effectiveness of the second cochlear implant; concerns regarding the time of receipt of the second cochlear implant; continuous advances in technology and the possibility that present-day CIs may preclude the recipient from future enhanced developments; and ultimately the significance of the potential outcomes for each individual recipient.

## **2.2 Potential benefits of bilateral cochlear implants**

"The expected benefits of bilateral cochlear implantation are based on known deficits experienced by both unilateral cochlear implant users as well as individuals with unilateral profound hearing loss" (Peters, 2006:2). Adults with a sudden unilateral hearing loss report a dramatic decrease in speech understanding, especially in the presence of background noise, as well as marked impairment in the ability to hear sounds originating on the side where they experience the hearing loss. Consequently, many of these individuals withdraw from social and occupational contexts that present challenging or complex acoustic environments. It is evident that a hearing loss can have many ramifications that affect more than one area of a person's life. This calls for effective intervention and Peters (2006:3) suggests that BCIs can be of significant help to those individuals in search of binaural hearing experience.

Researchers report that improvements in speech intelligibility and spatial hearing with BCIs are brought about by binaural phenomena. As explained earlier, the summation effect allows for the signal processing of sound input from two sides to provide a better representation of sound and allows one to separate noise from speech. The more common phenomena, the head shadow and squelch effects, enable the ear that is closest to the noise to receive sound at a different frequency and with different intensity, allowing the user to differentiate between the noise and the sound and to identify the direction of sound. In a study by MED-EL (2003),

bilateral cochlear implant users not only showed consistent improvements in speech discrimination and sound localization tasks, but also signal-to-noise ratios and sentence scores that were higher with BCIs than with unilateral cochlear implant use. Cochlear Limited (2005) report substantial benefits in subjects' ability to discriminate speech, especially when the speech signal and interfering noise come from different locations.

In view of these findings, improved sound localization is often considered an additional benefit of BCIs (Brown et al., 2007:316; Peters, 2006:3). Sound localization is made possible by the central auditory system's ability to calculate minute differences in the characteristics of sound arriving at each ear. The brain calculates differences in sound intensity, phase, frequency spectrum and arrival time between the two ears to determine the origin of sound (Peters 2006:2). To localize sound in the vertical plane (up and down), or when time and intensity cues between the two ears are ambiguous, spectral (pitch) information is used to calculate differences. In listeners with normal hearing the shapes of the outer ear and ear canal change the intensities of all the pitches arriving at the ear (by reflecting them differently) to determine the location of sounds in the vertical plane. According to Advanced Bionics Corporation (2004), listeners with normal hearing can tell where sound is coming from in the horizontal plane (at ear level) with an accuracy of approximately 14 degrees.

MED-EL (2003) reported that some BCI users were able to locate sound sources in the frontal horizontal plane with an average deviation in the order of 15° compared to the average deviation of approximately 50° with unilateral implant use. The decreased deviation in localization acuity is indicative of a positive bilateral advantage. Localization testing conducted in more recent studies by Gouws (2005) and Tyler, Noble, Dunn and Witt (2006:113) also found improved results in localization tasks with BCIs, as opposed to their subjects' performance under monaural conditions. Some manufactures consider the success people have with BCIs to be attributable to technical factors that distinguish their cochlear implant devices from other manufacturers' devices, and factors that make them especially well-suited for bilateral cochlear implantation. For example MED-EL cochlear implant devices are distinguished by a combination of high-rate stimulation and

deep insertion of the electrodes that provide the recipient with maximum acoustic information across the whole cochlea and good channel separation. This combination allows the auditory system to extract binaural clues more effectively.

In addition to audiometric or objective benefits, BCI recipients also report positive experiences in everyday listening conditions, which may support the improved audiometric test scores when determining the total benefit. MED-EL (2003) is among the manufacturers that included subjective reports in their research to determine the total benefit of BCIs. Results show that not only does bilateral cochlear implantation have the potential to provide its users with improved hearing in quiet and in noise, spatial hearing, and better sound quality, but (more significantly) the users reported that the objective improvements enhanced their hearing experience in everyday listening conditions. They reported a fuller and more natural experience of sound, an increased ability to distinguish between sounds, easier and better speech discrimination, and improvements in acoustical orientation abilities (MED-EL, 2003, accessed May 22, 2007).

Relatively few studies, however, acknowledge that the benefits of binaural hearing may not only be reflected in improved test scores, but also in subjective reports of more natural hearing and improvements in the recipients' quality of life (QOL). For this reason, the current study included measures of subjective performance. Although BCIs potentially offer a number of positive outcomes related to changes in QOL, it is important to compare these potential subjective outcomes with BCIs to some reported subjective outcomes with unilateral CIs. Wayman (2001) investigated the impact of unilateral CIs on the QOL of postlingually deafened adults and found that CIs exerted a positive impact on the QOL of the majority of the subjects in her study. She used and adapted the International Classification of Functioning and Disability framework (ICIDH-2) developed by the World Health Organization in 1999, and investigated the subjects' impairment, their participation in activities and contextual factors in detail. The results revealed that unilateral CIs can have a positive impact on all the domains investigated and consequently exert an influence on the QOL of the cochlear implant user (Wayman, 2001:47). Significant improvements in categories concerned with communication, feelings of being a burden, isolation, and relations to friends and family have also been

reported. Mo, Lindbaek and Harris (2005:193) found that unilateral CIs showed the potential to reduce the degree of anxiety and depression associated with hearing loss, in this way contributing towards QOL. A study by Hallberg and Ringdahl (2004:119), revealed increased self-worth and involvement in social life, a sense of harmony and feelings of equity and accountability. It is evident that there is a range of potential subjective outcomes with unilateral CIs that may vary among cochlear implant users, but ultimately bring positive change to the users' QOL. The potential subjective outcomes of CIs include the following (Schramm, Chenier, Armstrong, 2008):

- Better speech understanding compared to a hearing aid;
- Improved ability to talk on the phone and better appreciation of music;
- Improved environmental awareness and responsiveness;
- Less dependence on family members for everyday living and facilitation of communication with family and loved ones;
- A reconnection with the world of sound;
- Less loneliness, depression and social isolation and
- More independence, self-esteem, social interaction and employment opportunities.

It is evident that a unilateral cochlear implant can have a remarkable effect on many aspects of a recipient's life. One would anticipate that receipt of a second cochlear implant will not only enhance the effects of the first but bring novel changes in both objective and subjective measures. Peters (2006:1) states that it is important to maintain perspective and emphasize to candidates that despite potential objective and subjective benefits, BCIs are still unable to provide a recipient with 'normal' hearing. Tyler et al. (2006:116) concur and state that the performance of listeners with BCIs with regard to binaural hearing is improving with each advance in technology, but is still far inferior compared to the performance of listeners with normal hearing. This inferiority along with other limitations reported in research, have led some researchers to question the efficacy of BCIs as intervention type. Their reports counteract some of the positive outcomes suggested by other researchers.

### **2.3 Limitations of and negative commentary on bilateral cochlear implants**

The latest policy statement by Aetna (2007) raises matters that are worth investigating. The statement acknowledges that in listeners with normal hearing, binaural hearing allows for sound localization and speech discrimination, but expresses doubt whether such benefits are attainable with BCIs. The authors of the policy statement based their assumption on the electronics of a cochlear implant, which directly stimulates the auditory nerve and supposedly does not preserve the fine structure of the acoustic waveform at each ear. The report points out that until date, manufacturers have not yet developed CIs specifically designed for bilateral use. According to the authors, bilaterally implanted persons merely use two separate signal processors, one controlling each ear, with independent automatic gain control circuitry. This implies that the two unilateral processors are not temporally coordinated and may not preserve the fine temporal differences in sound that facilitate sound localization. Furthermore, the statement declares that there is inadequate support for the greater effectiveness of BCIs in improving hearing when compared to a unilateral cochlear implant, and that Cochlear Limited and other cochlear implant manufacturers have promoted BCIs without submitting evidence to the Food and Drug Administration (FDA) of the efficacy of CIs used for bilateral stimulation.

Although the report published on the Aetna website (2007) raises matters that demand investigation, the legitimacy of the report is questionable. The report reveals no evidence that the statements contained in it represent anything more than the opinions of the six co-authors involved, and there is no reference in the paper to indicate that the statements represent the position of any manufacturing company or government agency. The policy statement is therefore not considered an evidence-based guideline and several factors mentioned in the policy statement are contradicted by better controlled studies. These include the studies conducted by the different manufacturers and their reports of the success they have achieved with technologically more advanced devices that are especially well suited for bilateral implantation. Notwithstanding some of the manufacturing companies' success with their cochlear implant devices, more extensive investigation is needed

to confirm the overall benefit of attaining a second cochlear implant as intervention type.

A technical report by the American Speech Language Hearing Association (ASHA) on CIs, published in 2004, came to the following conclusion: "Bilateral implantation is currently being studied in a limited number of cochlear implant recipients with mixed results. In some cases, recipients do experience enhanced speech understanding, especially in noise; in other users, the improvement in speech understanding compared with unilateral performance is minimal or absent and the primary advantage of binaural implantation is sound localization. Bilateral cochlear implants' outcomes to date are encouraging but inconclusive due to the limited number of subjects and the scope of the projects. There is a clear need for further exploration of the many variables that can affect the performance of people with binaural implants before widespread use is warranted" (ASHA, 2004:27).

In 2006, the Swedish Council on Health Technology (SBU) conducted a comprehensive assessment of evidence supporting BCIs in children. Although their assessment was concerned with children, the findings may apply to the benefits experienced by adults. The SBU concluded that the data supporting BCIs in children, is insufficient to reach reliable conclusions about the effectiveness and safety of BCIs. In reviewing the evidence, the SBU found only a few scientific studies, none of which included a control group, that have assessed the benefits of BCIs. Studies using a child's data as his / her own control have reported improvements in speech discrimination and directional hearing with two implants. Because of their design, these studies provide merely indications and not evidence (SBU, 2006). The SBU (2006) emphasizes that well-designed, scientific studies are needed to determine whether a second implant yields positive effects which outweigh the increased risk for complications. According to the SBU report in 2006, results from clinical studies on complications of unilateral CIs in children show complication rates between two percent and 16 percent. According to this calculation a second cochlear implant could double the risk for complications. Furthermore, the SBU claims that device manufacturers have made allegations that BCIs will substantially improve academic and social performance, without providing any direct evidence of such benefits. In conclusion, the SBU strongly recommends



that controlled clinical outcome studies should be conducted to evaluate the potential benefits of BCIs, as available evidence consists mostly of small case studies and individual case reports.

Although some authors repudiate the significance of individual case reports, the single case study conducted by Gautschi (2003) discusses two key issues that are relevant for any candidate considering a second cochlear implant. These issues are the additional expenses involved in maintaining both CIs, and the surgical risks involved. Surgical risks have been proven to be minimal, but some authors point out that any risk, whether minimal or immense, remains a 'risk'. According to the FDA (2006, accessed September 30, 2007) surgical risks during a CI procedure may include the following: the possibility of an infection; the possibility that the small amount of residual hearing in the operated ear will be lost; discomfort or numbness around the implanted ear; temporary dizziness, tinnitus, taste disorders, and facial nerve injury. Consideration of the vestibular function and balance history of the person is prudent prior to both unilateral and bilateral implantation.

This discussion leads to yet another important subjective factor, the risk / benefit ratio that has proven to be more favourable for unilateral than for bilateral cochlear implantation. This is especially true when bilateral cochlear implantation is performed sequentially, the approach most commonly used in South Africa. Brown et al. (2007:317) explain that the risk / benefit ratio favour unilateral cochlear implantation because the risk of a second implant is just as great as with the first, but the additional benefit is not nearly as great. Many clinicians inform their patients or families who are considering a second implant that the risk is equal to 100% of the first operation, but the benefit only increases by a factor of approximately 20% (Brown et al., 2007:317). The same is true for the cost / benefit ratio with sequential cochlear implantation, because the cost is doubled, while the benefit is increased to a lesser degree.

For this reason, authors such as Summerfield et al. (2006) have raised the question whether the potential benefits that BCIs may offer, are outweighed by the increased cost. Summerfield et al. (2006) conducted a study to investigate the hypothesis that the gain in health utility from receipt of a second implant is as small as that

estimated in an earlier study (Summerfield et al., 2002). Their conclusion was that more QOL would be gained for every Euro / Dollar spent by providing one implant each to two people rather than by providing two implants to one person and no implant to another. Summerfield et al. (2006) found that any benefits from BCIs were modest and offset by negative effects to such an extent that the improvements in QOL were insignificant. According to the report of Aetna (2007) this study is the only randomized controlled clinical study on BCIs published to date. Few other studies have investigated the cost-effectiveness of BCIs within the framework of QOL.

The earlier study by Summerfield et al. (2002) provided no support for the idea that it could be acceptably cost effective to provide a second cochlear implant to postlingually deafened adult persons, who already use a cochlear implant unilaterally. In addition to excessive costs, Schramm, Chénier and Armstrong (2008) list some other disadvantages associated with CIs in general. These disadvantages also apply to people with BCIs:

- CIs are electronic devices and at times the external pieces can malfunction and require replacement;
- Cochlear implant recipients and / or their families may have unreasonable expectations such as wanting to understand speech from listening alone and not using speechreading cues or normal gestures that support verbal messages;
- Cochlear implant users often still struggle to hear in difficult listening situations eg. when distance and background noise are present;
- There is a persistent myth that CIs restore normal hearing. The reality, however, is that they can provide improved speech discrimination and sound quality;
- After cochlear implantation, a learning process is required to obtain the maximum benefit from the device;
- When the speech processor is turned off, the user does not perceive any sound;
- Choosing to get a CI is a very personal decision and it is a process that needs to be examined with a competent CI team.

Schramm, Chénier and Armstrong (2008) conclude that there are opportunities for improving binaural performance, but challenges for quantifying the performance, still remain (Tyler et al., 2006:118). Ongoing research and the evaluation of assessment protocols are essential to guarantee not only the validity of the assessments used, but also and more importantly, the legitimacy of BCIs as intervention strategy.

Lastly, a relevant consideration that has recently received increasing attention is to assess whether the second cochlear implant will preclude the implantation of yet a newer device at some future time. In the past, some professionals recommended that one ear should be preserved for future superior devices that could result from improved technology (Peters, 2006:6). This continues to be an important consideration in addition to individual factors such as hearing thresholds, auditory nerve functioning, and the recipient's current functioning when making the decision to have the second ear implanted with an upgraded device.

The assessment of benefits to be gained from a second cochlear implant is discussed in the following section.

#### **2.4 Assessment of the benefits of bilateral cochlear implants**

Considering the wide range of potential benefits, alleged inadequacies in cochlear implant devices and reported limitations in research, continuous assessments of each bilateral cochlear implant recipient's performance is imperative to determine the actual outcomes of BCIs. From current literature and studies, it appears that each research center has developed its own assessment protocol to determine the benefits of BCIs. Although the methods used to assess the benefits of BCIs differ among studies, a pattern of benefits has emerged from various objective assessments. Worldwide, numerous researchers concur that the two main advantages of BCIs are the potential to improve speech discrimination abilities both in quiet and in the presence of interfering noise, and improvements in the ability to localize sounds in space (Litovsky et al., 2004; Peters, 2006; Brown et al., 2007). Given the two main advantages of BCIs (i.e. improvements in speech recognition and localization), this section provides a brief discussion of the methods that were

employed in the current research study as to determine these specific outcomes as well as to assess the outcomes in functional everyday communication.

#### 2.4.1 Determining the benefits of BCIs using open set speech discrimination testing

Patients seeking intervention for their hearing loss often do so because they have difficulty understanding speech or because family members believe they have difficulty understanding the speech of others (Katz, 2002:96). The direct assessment of speech recognition is therefore considered important because of its paramount importance to patients and their families. Speech recognition tests (SRTs) serve as cross verification of the puretone air conduction threshold results and as baseline when determining the presentation levels for suprathreshold speech recognition tests, whereas speech discrimination scores reveal the person's ability not only to hear words but to identify them.

Speech discrimination testing involves the presentation of selected monosyllabic word lists (a list of one-syllable words with beginning and ending phonemes chosen according to their frequency of use in conversational speech), at an easily detectable intensity level (Katz, 2002:97). The speech stimuli can be presented through live-voice presentation or pre-recorded test material. In both cases the loudness of each word should be balanced and the material presented at a standard distance in a prescribed acoustic environment (Clark, 2003:714).

Although both closed sets of words (i.e. a restricted number of items for discrimination and recognition) and open sets of words (i.e. outright recognition of words with no contextual clues) can be used in speech perception testing, open sets of words more closely predict the ability of a person to communicate in everyday situations. One open set of words, the AB-word test, was developed by Arthur Boothroyd in 1968 (Clark, 2003:714). Each list contains 10 monosyllabic words that are scored as the percentage of words or phonemes correct. The speech discrimination score (SDS) is thus the percentage of words correctly identified. Scores are usually labeled as excellent, good, fair, or poor (Katz, 2002:107). The Northwestern University NU-4 and NU-6 monosyllabic word tests as well as the Phonetically Balanced Kindergarten word test (Haskins, 1964 in Clark, 2003:714) are also frequently used and scored as words and phonemes

correct (Clark, 2003:713). Results of these tests allow the audiologist to identify the phonemes the patient has difficulty hearing at a particular intensity level (Katz, 2002:107).

In addition to word-recognition scores, the perception of speech may also be assessed through the percentage of key words in sentences correctly identified. Examples of word-in-sentence test materials include the 'Central Institute for the Deaf (CID) Everyday sentence lists' (Davis & Silverman, 1978), the 'Bamford-Kowal-Bench (BKB)' sentences (Bench & Bamford 1979), the 'Speech Intelligibility Test (SIT)' (Magner, 1972 in Clark, 2003:714) and the 'Glendonald Auditory Screening Procedure (GASP)' (Erber, 1972 in Clark, 2003:714). Sentence recognition and word recognition tests can also be modified by presenting the stimuli in the presence of competing background noise, thereby creating a more realistic presentation of everyday listening conditions. Improvements in localization acuity may provide subtle advantages in speech recognition due to subconscious head positioning. For this reason, localization testing was included in the current study.

#### 2.4.2. Determining the benefits of BCIs using a localization test

As improved localization ability is expected to be one of the main outcomes with BCIs, the assessment and analysis of the ability to localize should be carefully executed. In CI studies, localization abilities are typically determined by comparing the minimal audible angle (MAA) values obtained in the unilateral condition with those of the bilateral condition (Firszt, 2008:751). A minimum audible angle (MAA) is estimated to characterize a listener's ability to distinguish between two locations. Shub, Carr, Kong and Colburn (2008:3134) conducted a MAA experiment during which subjects were presented with a series of two-interval trials. The first interval was presented from the virtual reference location (fixed for each run of 90 trials), and the second interval was from the virtual comparison location (to either the left or right of the reference location). The left and right comparison locations were presented with equal probability, and the subjects were instructed to report whether the comparison location was to the left or to the right of the reference location. A level randomization (chosen independently from interval-to-interval and trial-to-trial)

was applied to the stimulus in each interval. There was 200 ms of quiet between each interval. Trials were self-paced, and the subjects received correct-answer feedback after every trial.

Another method of assessing localization acuity is with a virtual-speaker array. Equally spaced loudspeakers are usually mounted in a horizontal plane at ear level, in an arc that spans the frontal hemi-field and / or full 360 degrees azimuth. When a signal is produced on the horizontal plane, its angle in relation to the head is referred to as its azimuth, with 0 degrees ( $0^\circ$ ) azimuth being directly in front of the listener,  $90^\circ$  to the right, and  $180^\circ$  being directly behind. If a signal arrives at the head from  $90^\circ$  azimuth, the signal has further to travel to reach the left ear than the right. This results in a time difference between the two ears with regard to when the sound reaches the ear. This difference is detected by the auditory system, and aids the process of identifying the sound source (Cochlear Limited, 2005, accessed February 14, 2007).

Other studies investigating sound localization acuity have used a setup that included loudspeakers mounted on an arc with a radius of 1.5m at ear level, with speakers positioned every  $10^\circ$  from  $-70^\circ$  to  $+70^\circ$  (Litovsky et al., 2006:84; Tyler et al., 2002). It is important to consider that only the frontal hemi-field is then included in the test array and those findings are limited to the subjects' ability to identify the sound source when presented from the front. In a report in 2005, Cochlear Limited (accessed February 14, 2007) refer to numerous studies conducted in the United Kingdom (UK), United States and in German centers. In all but one of the studies mentioned, localization acuity was also only assessed in the frontal hemi-field. The researchers at the German center produced the only study that included 12 loudspeakers at  $30^\circ$  intervals in a full circle around the subject. MED-EL (2003, accessed May 22, 2007) also assessed localization acuity at different centers and only included the frontal hemi-field. Although their subjects were able to locate sound sources with an average deviation in the order of  $15^\circ$ , the current researcher is reluctant to agree with their statement that localization acuity is restored with BCIs (MED-EL, 2003, accessed May 22, 2007) if only the frontal hemi-field was included in their test array.

In real life conditions, different sounds may originate from complex acoustic environments. This consideration led the current researcher to realize the need for more subjective confirmation of the audiometric findings and the importance of including subjective measures (eg. real life experiences) to verify any audiometric findings.

#### 2.4.3 Determining the benefits of BCIs using subjective measurements

As early as in 1982, Cary, Berliner, Wexler and Miller (in Knutson, Johnson and Murray, 2006:280) and again in 1990, Pettigrew (1990, in Fitzpatric et al., 2006:193) highlighted the importance of a qualitative approach in evaluating the outcomes of CIs in real life contexts, to generate functional results for potential candidates. Previous studies also suggested that the benefits perceived by cochlear implant users are not fully captured by traditional clinical assessment protocols, and the inclusion of a qualitative approach has been described as mandatory (Zwolan, Kileny & Telian, 1996 in Fitzpatric & Schramm, 2006:193). The current researcher is of the opinion that the inclusion of subjective measurements in determining the potential and final benefit of BCIs may provide data that can take into account the individual differences among subjects with BCIs and explain the effect that individuality may have on the outcomes of each BCI user. In addition, the reports of personal experiences and the enriched descriptions by BCI recipients can be very useful in verifying and supplementing test scores and other objective data.

It is useful to recall that the main objective of bilateral cochlear implantation is to improve *speech recognition under everyday listening conditions* (Brown et al., 2007:316). Although most studies find improvement in speech discrimination and localization acuity, both equally important for improved speech recognition, fewer studies evaluate whether these potential benefits are perceived in everyday listening conditions. Only a few researchers have included the patients' perspectives on their own performance in speech discrimination tasks and spatial separation in everyday listening conditions as subjective measurement. Of these few studies, most include questionnaires and profiles in an attempt to determine the benefits as perceived by the subjects in everyday listening situations. Peters (2006:4) reported that Cochlear Limited incorporated patient satisfaction and

benefit questionnaires in their multi-center studies, and that both prelingually and postlingually deafened adults overwhelmingly favoured bilateral implantation. Gautschi (2003) used two distinctive standardized questionnaires, viz the Glasgow Hearing and Benefit Profile (GHABP) (Gatehouse, 2000) and the Nijmegen Cochlear Implant Questionnaire (NCIQ) (Hinderlink, Krabbe & Van den Broek, 2000), as well as an interview, to collect the necessary subjective data. Gouws (2005) used a self-generated questionnaire to evaluate the benefits in two adult BCI recipients' quality of life.

The NCIQ was specifically designed for use with adult cochlear implant users and was originally utilized in a research project designed to develop a quantifiable, self assessment, health related QOL instrument (Hinderlink, Krabbe & Van den Broek, 2000:757). The 'SSQ rating scales' comprise three scales that deal with the subjective measurement of three areas, generally thought to improve with bilateral cochlear implantation (Gatehouse & Noble, 2004:85). The three areas are: speech discrimination, spatial orientation, and quality of sound. Wayman (2001:54) designed a questionnaire in order to investigate the psychosocial impact of cochlear implants on the quality of life of postlingually deafened adults. In accordance with the 'International Classification of Functioning and Disability' (developed by the World Health Organization in 1999) the questionnaire was divided into six sections, namely: personal contextual factors, physical functions, communication activities, daily activities, social participation and environmental contextual factors. These factors are often included and thought to exert an influence on a person's quality of life.

The influential World Health Organization Quality Of Life (WHOQOL) group defines quality of life (QOL) as "an individual's perspective of their position in life, in the context of their culture and value systems in which they live, and in relation to their goals, expectations, values and concerns incorporating physical health, psychological state, level of independence, social relations, personal beliefs and their relationship to salient features of the environment" (WHOQOL, 1995, in Phillips, 2006:33). Another reference suggests that QOL is the result of the difference between people's expectations of themselves and what they actually achieve (Staquet, Hays & Fayers, 1998, in Wayman, 2001:3). It is obvious from



these definitions of QOL, that QOL measurements are a relevant means to obtain insight into the understanding that people have of what they have gained or lost from a particular intervention. Other subjective measurements that have been included are functional performance, psychological adjustment and status, and cost effectiveness. These subjective measurements are discussed below.

“Functional performance” is considered a viable assessment tool in determining an individual’s contentment with her / his assistive devices. Functional performance refers to an individual’s performance with her / his assistive device in everyday listening conditions. Most studies investigating the individual’s functional performance include the assessment of the benefit in QOL. The benefit in QOL with hearing aids (HAs) compared to the benefit in QOL with CIs in adults has also been investigated. Cohen, Labadie, Dietrich and Haynes (2004:413) conducted a study to compare the QOL benefit received from CIs and HAs among adults with hearing loss. The results show that compared to HA users, CI users report twice as much overall QOL improvement. Analysis of variance show greater QOL benefit with CIs than with HAs across the physical, psychological, and social sub-domains. The conclusion drawn from that study is that CIs provide benefits for those with profound hearing loss, that are at least comparable to the benefits that HAs provide to those with less severe hearing loss. Although HAs may be compatible with CIs in individuals with severe hearing loss, the compatibility declines in individuals with severe-to-profound hearing loss. Perhaps the statement made by Peters (2006:1) is the rule rather than the exception: “in the case of patients with severe-to-profound hearing loss, effective binaural hearing requires bilateral cochlear implantation.”

Knutson et al. (2006:280), who also investigated the impact of cochlear implants on psychological domains, speculated as to whether there is reason to believe that the psychological status of persons seeking CIs has changed over time. Their assumption was that if persons currently seeking CIs are less desperate and less distressed than earlier implant recipients, then improvement in psychological status would be a less suitable goal for implantation. At the time cochlear implants were introduced as a prosthetic device, it was suggested that psychological benefit was among the outcome measures that could be considered in evaluating success

(Crary et al., 1982; Miller, 1978, in Knutson et al., 2006:290). Consequently, Knutson et al. (2006:280) conducted a study designed to determine whether psychological benefit remains an appropriate goal for contemporary implant candidates. No evidence was found that the psychological status of implant candidates has changed across time, suggesting continued psychological benefit for persons receiving cochlear implants (Knutson et al., 2006:290).

Additionally, Knutson et al. (2006:279) explored mechanisms by which profound deafness could contribute to psychological difficulties for implant candidates' spouses. The assumption was that because spouses of implant candidates also experience elevated levels of loneliness and social anxiety, the psychological status of the spouses of implant recipients need also be investigated over time. The results showed that, regardless of marital status, acquired profound deafness was associated with reduced engagement in pleasant social activities (Knutson et al., 2006:290). The results of their studies provide considerable evidence that reduced psychological distress and increased social participation in pleasant activities continue to be suitable goals of cochlear implantation (Knutson et al., 2006:290).

Potential improvements in the QOL of bilaterally implanted recipients were also included as part of a UK sequential study measuring the incremental benefit of the second cochlear device (Cochlear Limited report, 2005, accessed February 14, 2007). Four areas of benefit were included in the study, namely: spatial hearing and speech discrimination in noise, otologically relevant QOL, generic QOL, and a health utility index (i.e. a comprehensive, quantitative measure of health status). Findings show that receiving the second implant has significant incremental beneficial effects on spatial hearing and otological aspects of QOL, but not for the more generic QOL and health utility. That is, BCIs will improve QOL at least as much as a unilateral implant will, in the better performing ear. Cochlear Limited (2005, accessed February 14, 2007) explain that if the overall cost of BCIs could be made only 10% to 20% more than the current cost of a single implant, then the cost-effectiveness of BCIs would be acceptable within the cost-effectiveness framework in the UK. Cochlear Limited (2005, accessed February 14, 2007) admits that the analysis did not consider some factors that may improve the overall cost effectiveness. These include simultaneous bilateral implantation that may reduce

costs to a single hospital stay, and streamlining bilateral speech processor fitting methods, which may reduce the time of clinical contact (Cochlear Limited report, 2005, accessed February 14, 2007).

Summerfield et al. (2006) also investigated the cost effectiveness of a second cochlear implant by analyzing the benefit from BCIs using a cost-utility ratio. A cost-utility ratio is the ratio of the incremental cost of a treatment to the incremental benefit gained from the treatment. The investigators concluded that as a treatment option, the receipt of a second CI by postlingually deafened adults leads to improvements in self-reported abilities regarding spatial hearing, quality of hearing and hearing for speech, rather than to changes in measures of QOL. The multivariate analyses show that positive changes in QOL were only associated with improvements in hearing and were offset by negative changes associated with worsening tinnitus. Even in a best-case scenario, in which no worsening of tinnitus was assumed to occur, the gain in QOL was too small to achieve an acceptable cost-effectiveness ratio. Summerfield et al. (2006) stress that it is important to demonstrate that BCIs can lead to improvements in QOL, as such improvements underpin the 'effectiveness' component of the cost effectiveness ratio. The greater the incremental benefit, and the lower the incremental cost, the more cost-effective the new interventions is and the more likely it is to be funded. Cost effectiveness ratios can therefore be taken into account, when priorities for expenditure on interventions are set. At the current time, a cost-effectiveness study has never been undertaken in South Africa (Wiegman, personal communication, 2009).

In South Africa, the government does not provide funding or contribute towards a cochlear implant. Although an estimate 20,1% of the total South African population has some degree of hearing loss (Statistics South Africa, Census 2001, accessed February 21, 2009) cochlear implants are still considered a low priority when expenditure on intervention are set. It is thought provoking to compare the CI situation to the funds allocated for 21,5% of people in South Africa, estimated to be living with HIV / AIDS, a deadly infectious disease (UNAIDS, 2004, report on the Global AIDS Epidemic, accessed February 22, 2009). Consequently, the majority of patients that apply for a cochlear implant have to rely on other means of financial support, often the private health sector which is financed by the medical aid

industry. At the current time only 16% of the South African population has medical aid coverage, while the public sector is responsible for 84% of the population. It is clear that a large number of people with hearing loss in South Africa may not have the resources to be able to obtain a cochlear implant as intervention strategy.

Considering the exorbitant costs involved in attaining a second cochlear implant, this study proposed to investigate both the objective and subjective benefits as a means to better understand the outcomes of this particular intervention type for some South African recipients. The current study aimed to not only evaluate the audiometric benefits of BCIs under controlled conditions, but also to evaluate perceived benefits subjectively, using questionnaires relevant to everyday listening conditions, including a questionnaire for each BCI subject's significant other person.

## **2.5 Conclusion to Chapter two**

International studies have examined the contributions of BCIs to the various advantages of binaural hearing. Most studies find the improvements with BCIs related to the head shadow effect and some BCI users also show benefits that require neurological processes (i.e. binaural squelch and binaural summation effects). Depending on the user's ability to capitalize on the binaural effects, BCIs may provide significantly greater improvement than single implants in the user's ability to localize sound and discriminate speech in the presence of noise. Individual differences and variables, such as the BCI user's experience with bilateral listening and age of cochlear implantation, can be difficult to control and evidently predict the outcomes of a second cochlear implant. More comprehensive and subjective measures may support the test scores in verifying the total benefit perceived by each user in everyday listening conditions. The inclusion of a significant other person in the current study may provide a reliable way to verify the subjective outcomes. Data will be obtained from the report of outcomes as perceived by the significant other person as well as by the BCI-user, in everyday listening conditions.

## **2.6 Summary**

Chapter 2 presents a critical review of current literature on the objective and subjective outcomes of BCIs and related issues with regard to adults. Research provides evidence that it is possible for most BCI users to gain objective benefits through head shadow and for some users also through binaural squelch- and summation effects. Some BCI users also report subjective benefits including better quality of sound, improved spatial orientation and better speech discrimination in a variety of contexts. Notwithstanding the potential benefits, the outcomes of BCIs may vary among individuals and in some cases can be outweighed by the exorbitant costs involved in obtaining the second device. Local investigation is critical to help define the benefit of a second cochlear implant. Local research may assist patients with less favourable historical factors and challenging co-morbid conditions to better understand the potential benefits of BCIs. In addition, the reported outcomes of adults with contemporary implants may assist in determining whether improved binaural gains can be attained with even newer processing strategies and more advanced devices.

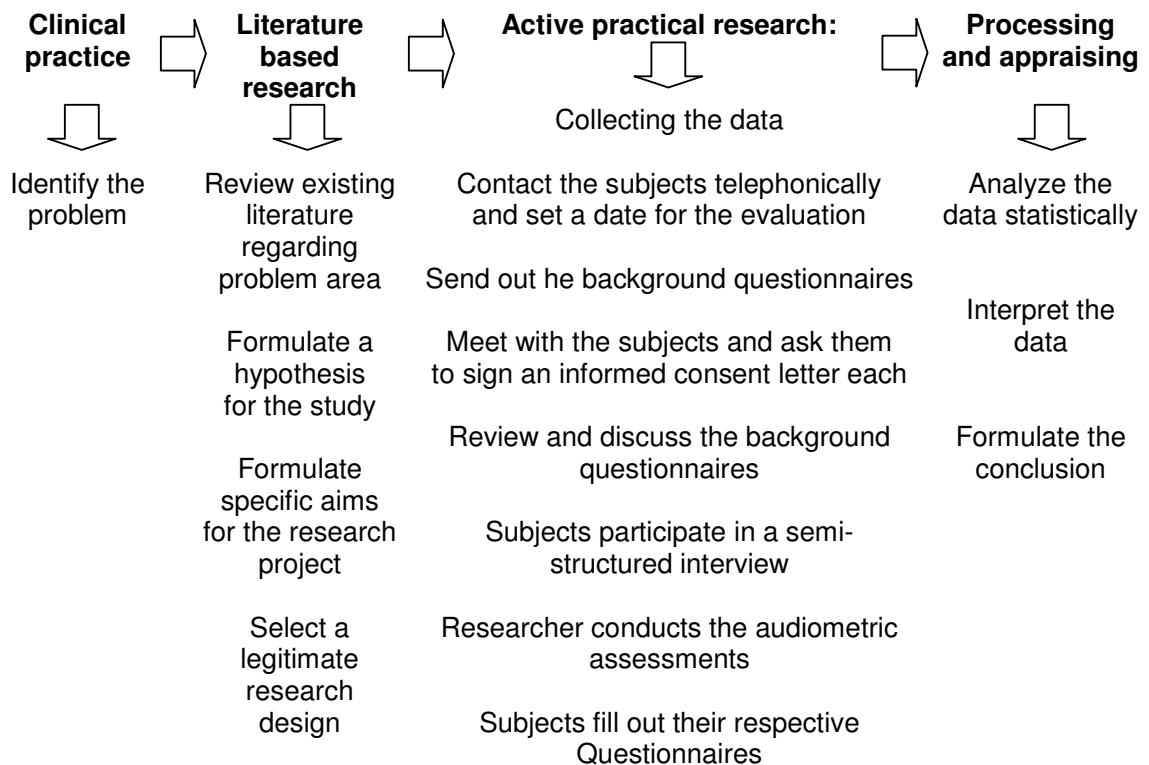
## CHAPTER 3

### METHODOLOGY

Chapter 3 describes the research method in detail. Each part of the research method is thoroughly explained and its inclusion justified. Throughout the chapter, ethical issues are affirmed and the research method is presented in such a way that any reader or potential researcher will be able to duplicate the study.

#### **3.1 Introduction**

Chapter 3 provides an outline of the study’s conceptual framework across the five chapters it encompasses. A framework involves bringing together all the phases that constitute a legitimate research study. Figure 3.1 illustrates a personalized, concise layout of the different phases involved in conducting the current research study, using both quantitative and qualitative measures.



**Figure 3.1: Phases of the study**

Figure 3.1 depicts the various phases of the current research study. Each of the different phases follows a preceding activity and leads to the next. A more detailed

discussion of the course and complexities of each phase is provided in the sections to follow.

### **3.2 Research aims**

Research aims are generally set to help the researcher achieve specific goals within the research project. The main aim of any research is usually reached through achieving several sub-aims, which are the different elements imbedded in the complexity of the main aim.

#### **3.2.1 Main aim**

The main aim of this study was to investigate the outcomes of bilateral cochlear implants in adults.

#### **3.2.2 Sub-aims**

In order to realize the main aim, the following sub-aims were formulated:

- To determine the objective auditory outcomes of subjects with BCIs.
- To determine the self-reported subjective outcomes of subjects with BCIs.
- To determine the subjective outcomes of BCIs as perceived by significant other persons relating to the subjects with a BCIs.
- To investigate the individual correlation between the objective outcomes and subjective outcomes for each subject with BCIs.
- To investigate the correlation between the objective outcomes and the subjective outcomes as perceived by the significant other person.

### **3.3 Research design**

In this study a combined research approach, comprising both quantitative and qualitative approaches, was used to collect, analyze, and interpret the data. According to Cresswell (2003:15), the concept of using mixed methods first originated in 1959, when Campbell and Fiske (1959, in Cresswell, 2003:15) used

multiple methods to study the validity of psychological qualities. This approach proved so successful that Campbell and Fiske encouraged others to employ their multi-method matrix when considering multiple approaches for data collection in future studies.

The current research study followed their recommendation and used both quantitative and qualitative approaches. The quantitative approach allowed the researcher to describe and objectively assess the audiometric (objective) outcomes of the subjects with BCIs. It also enabled the researcher to answer questions about relationships among measured variables with the purpose of explaining, predicting, and controlling a phenomenon (Leedy & Ormrod, 2005:94). The phenomenon explored in this study was that individuality appears to be the key factor determining the outcomes of bilateral cochlear implants (BCIs). The researcher wished to investigate whether the objective outcomes of BCIs may lead to diverse subjective outcomes or changes in the quality of life (QOL) of bilateral cochlear implant recipients. The explorative nature of the qualitative approach enabled the researcher to determine the subjective outcomes as perceived by the subjects with BCIs and their significant other persons. The qualitative data was also used to answer questions about the complex nature of the phenomenon from the subject with BCIs' perspective and from her / his significant other person's point of view (Leedy & Ormrod, 2005:94).

A mixed-method research design was selected to obtain and analyze the data in this study. According to Creswell and Clark (2007:5), 'mixed-method research' is a research design with philosophical assumptions as well as several methods of inquiry. The philosophical assumptions guided the collection and analysis of the data and assisted in combining the qualitative and quantitative approaches in many phases throughout the research process. This also enabled the researcher to seek out several different types of sources that provided insight in the outcomes of BCIs.

Accordingly, the elements of both approaches, i.e. quantitative and qualitative methods of inquiry, helped facilitate the interpretation of the combined data that converged into reliable conclusions. This progression is generally known as triangulation. According to Leedy and Ormrod (2005:99), triangulation is common in mixed-method designs and occurs when multiple sources of data are collected with



the expectation that they will converge to support a particular hypothesis or theory. Ultimately, a mixed-method research design can utilize not only triangulation but also other elements that further rationalize the use of a mixed-method. Greene, Caracelli and Graham (1989, in Miles & Huberman, 1994:41) created a “list of purposes” for mixed research. Only the elements relevant to the current study are listed in the excerpt below:

- “Triangulation: seeks convergence, corroboration and correspondence between results from different methods;
- Complementation: seeks elaboration, enhancement, illustration and clarification of the results from one method with the results from the other;
- Initiation: seeks the discovery of paradox and contradiction, new perspectives of framework, the recasting of questions or results from one method with questions or results from the other and
- Expansion which seeks to extend the breadth and range of inquiry by using different methods for different inquiry purposes” (quoted directly from Miles & Huberman, 1994:41).

As the researcher collected extensive data on each subject and spent an extended period of time interacting with the subjects involved, a multiple or collective case study research design was also incorporated in this study. According to Leedy and Ormrod (2005:135), a collective study enables the researcher to make comparisons, build theory, and propose generalizations. In this study it allowed for the investigation of the correlation between the objective and subjective outcomes to determine the overall outcomes of each subject with a BCI. As the researcher investigated the real phenomena, this study made use of applied research.

### **3.4 Sample**

Sample selection is an important part of any study and ensures that the research aims are successfully accomplished. The criteria for the selection of subjects, the sample size, and a description of the subjects are discussed in the sections to follow.

### 3.4.1 Criteria for subject selection

The primary criteria for subject selection were that all subjects had to be 18 years or older, bilaterally implanted with cochlear implants, and clients of the Pretoria Cochlear Implant Program (PCIP). Other criteria that were also considered are listed and justified in Table 3.1 and Table 3.2 respectively.

**Table 3.1: Justification of criteria for the selection of subjects**

CRITERION	JUSTIFICATION
Subjects had to be clients of the PCIP, which is situated at the University of Pretoria.	This criterion was mainly set for logistic purposes. The PCIP was well within reach of all the subjects as mapping of the BCIs took place at the PCIP, conveniently located at the University of Pretoria. The researcher had access to the PCIP and once consent was granted by the head of the PCIP (Appendix A), information was easily obtainable.
Subjects had to have BCIs.	There is a general agreement that CIs are appropriate for people with bilateral profound sensory neural hearing loss, who do not gain significant benefit from conventional hearing aids. In search of binaural hearing, some unilateral CI users have received a second cochlear implant. High expectations have been set for BCIs that may exceed some recipients' actual outcomes. This called for an extensive investigation of all the subjects with BCIs.
Subjects had to be 18 years of age or older at the time of the research.	This study focused on adults. According to various resources, adults include persons of 18 years and older. No upper age limit was set because, depending on their physical health status and individual expectations, a person can receive an implant at any age.
Subjects had to have been implanted with their second device for at least a period of six months.	This study required that all the subjects had a minimum of six months of bilateral cochlear implant use. This was to ensure that all the subjects were accustomed to wearing both their devices, and that all the subjects were familiar with the sound and the use of the devices.

**Table 3.1: Justification of criteria for the selection of subjects (continued)**

CRITERION	JUSTIFICATION
Subjects had to be proficient in either English or Afrikaans.	Data collection was executed in the client's preferred language. All the material used and assessments conducted, were readily available in both languages as the majority of PCIP clients are either English or Afrikaans speaking. The researcher is also only proficient in these two languages.

Criteria considered, but not included for the selection of subjects, are listed and their omission justified in Table 3.2 below.

**Table 3.2: Justification of criteria not included for the selection of subjects**

CRITERIA NOT CONSIDERED	JUSTIFICATION OF OMISSION
Onset of hearing loss (prelingual or postlingual)	This study focused on the outcomes of adults with BCIs. As adults with a history of prelingual and postlingual onset of hearing loss had been implanted with BCIs in the PCIP, the onset of the adults' hearing loss was not considered necessary for the selection of subjects.
Type and model of cochlear implant (i.e. FDA approved ear level or body worn devices).	There is no clear-cut consensus that any one of the current available devices is superior to those of other companies. The type and model of the CI used were therefore not considered to be important considerations.
Processing strategies (CIS, ACE or SPEAK).	Research comparing CIS to SPEAK and CIS and SPEAK to ACE, confirm that cochlear implant adults have better speech discrimination in noise when using the ACE strategy than when using either CIS or SPEAK (Arndt, Staller, Hines and Ebinger 1999; Clark, 2003; Wiegman, 2007). As no comparison between the subjects was made, however, subjects using any processing strategy were included.

Given the justification of criteria considered and not included in the selection of subjects, a discussion of the sample size and the selection procedures followed.

### **3.4.2 Sample size and selection procedure**

Non-probability sampling was used to select the sample. This type of sampling has three distinctive variations which are referred to as convenience- sampling, quota-sampling and purposeful sampling (Leedy & Ormrod, 2005:206). In this study, purposeful (non-random) and convenient sampling applied. It allowed for the selection of *all* the subjects with BCIs within the PCIP. At the time the study was conducted, the PCIP had eight adult bilateral cochlear implant recipients who, according to the coordinator of the PCIP, conformed to the proposed selection criteria. Considering the logistic issues and accessibility to the PCIP, convenient sampling was used and all the bilateral cochlear implant recipients within the PCIP were chosen for this study.

In order to draw accurate inferences about the adults with BCIs in the PCIP all eight subjects were included in the study. A letter of consent (Appendix A) was sent to the head of the PCIP, Professor J.G. Swart, asking his permission to involve the subjects and to have access to their clinical file records. Once permission was granted, the subjects with BCIs and their significant other persons were telephonically informed about the research project. All eight subjects with BCIs were willing to participate in this study. The response rate in this study was thus very high. The relatively small sample size allowed for a more detailed and in-depth investigational study. This study was therefore concerned with the comprehensive analysis of the assessments of each subject. The respondents in this study included both the subjects with BCIs and their significant other persons. Both parties are from here on referred to as subjects.

Once the subject with BCIs and her / his significant other person expressed willingness to participate in the study, a mutually convenient date was set and the language of preference determined. The purpose of the research project and what was expected of the subjects were thoroughly explained. A week before the arranged date, the researcher telephonically reminded each subject of the upcoming evaluation date. Furthermore, the researcher sent a personally

addressed letter to each subject with BCIs, explaining the aims and procedures of the study. This letter (Appendix B) also served as a questionnaire as it requested background information of the subject with BCIs. Throughout this study, this letter is referred to as the ‘background questionnaire’ (Appendix B). The subject was asked to complete the background questionnaire and return it on the day of the evaluation. On the day of evaluation, before any investigation or further questioning commenced, each subject was asked to read and sign a letter of informed consent (Appendix C). Informed consent was obtained both from the subjects with BCIs and their significant other persons.

### 3.4.3 Description of the sample

Although the PCIP had eight bilateral cochlear implant recipients who conformed to the selection criteria, one subject preferred using monaural amplification through a unilateral cochlear implant. This subject was chosen to participate in the pilot study due to the limited amount of time she had worn her BCIs, as well as her inexperience with binaural hearing. Each subject with BCIs was asked to choose a significant other person to accompany them on the day of evaluation. Only three of the seven subjects with BCIs’ significant other persons were able to attend the day of evaluation. The remaining four ‘significant other people’ agreed, however, to participate and to willingly fax or electronically mail their comments and *Questionnaire for the significant other person* (Appendix F) to the researcher.

A total of seven subjects with BCIs and seven significant other people of the subjects with BCIs participated in this study. A description of the sample is presented in Table 3.3.

**Table 3.3: Description of the sample**

DESCRIPTIVE	N
Subjects with BCIs	7
<i>Gender of subjects with BCIs:</i>	
Male	2
Female	5

**Table 3.3: Description of the sample (continued)**

<b>DESCRIPTIVE</b>	<b>N</b>
Significant other people	7
<i>Gender of significant other person:</i>	
Male	2
Female	5
<i>Age at first implantation:</i>	
0-10 years	2
10-20 years	1
20-30 years	1
>30 years	3
<i>Mode of communication:</i>	
Oral communication	7
<i>Duration of single CI device use before receipt of a second cochlear implant:</i>	
0-5 years	1
5-10 years	5
15-20 years	1
<i>Did subject use bimodal amplification before obtaining her / his 2nd CI:</i>	
Yes	2
No	5
<i>Age at second implantation:</i>	
0-10 years	0
10-20 years	2
20-30 years	2
>30 years	3
<i>Preferred language:</i>	
Afrikaans	7
English	0

### **3.5 Data collection instruments and apparatus**

Data collection instruments, as well as various appliances were used in order to obtain the necessary information from the subjects.

### 3.5.1 Instruments and apparatus used for subjective data collection

The following data collection instruments, some developed by the researcher, were used to obtain all the necessary subjective data from the subjects. A detailed description of each instrument, some developed by the researcher, is provided below.

#### 3.5.1.1 Interview schedule: Semi structured interview (Appendix D)

The purpose of the semi-structured interview was to collect information regarding the subjective outcomes of BCIs in adults. Both closed-ended and open-ended questions were asked. The inclusion of both types of questions allowed for greater flexibility in exploring the subject matter. The semi-structured interview proved sufficient for the purpose of gaining an in-depth understanding of the subjects' own experiences with BCIs, some related to changes in their QOL. Although all the questions were created to examine experiences after the second cochlear implant activation, the subjects were asked to reflect on past experiences with a monaural cochlear implant. A tape recorder was also used as a back up strategy to support the written data.

#### 3.5.1.2 Questionnaires (Appendices B, E and F)

The researcher developed three questionnaires (Appendices B, E and F), of which two (viz. the background questionnaire and the *Questionnaire for the subject with BCIs*) had to be completed by the subject with BCIs and one (the *Questionnaire for the significant other person*) by the subject with BCIs' significant other person. The purpose of the researcher-generated questionnaires was to gain more in-depth information regarding the subject with BCIs' perceived outcomes both from the subjects with BCIs and from their significant other persons' perspective. The questionnaires also served to assist in obtaining a holistic view of each subject's perceived outcomes in areas concerned with QOL, including communication, contextual and psychosocial domains.

Prior to investigating the domains related to a person's QOL and prior to meeting the subjects on the day of the evaluation, the researcher asked the subjects with BCIs to complete a background questionnaire (Appendix B), their first data

collection instrument. The purpose of this questionnaire was to obtain demographic information, including the subject's medical and audiological history. In addition, this questionnaire explained the aims and procedures of the study, served as a reminder of the pre-arranged evaluation day, and helped determine whether the subject adhered to the selection criteria.

On the day of evaluation the subjects with BCIs were asked to complete the *Questionnaire for the subject with BCIs*, which was the second data collection instrument, (Appendix E). This questionnaire is a detailed data collection instrument, compiled by the researcher, and contains 49 questions of which 37 are closed-ended and 12 are open-ended. The significant other person of each subject with BCIs was also asked to complete a questionnaire on the day of evaluation, the *Questionnaire for the significant other person* (Appendix F). This questionnaire is a slightly shorter version of the *Questionnaire for the subject with BCIs* and contains similar questions. This questionnaire was also compiled by the researcher and contains 26 questions of which 19 are closed-ended and seven are open-ended.

The *Questionnaire for the subject with BCIs* and the *Questionnaire for the significant other person* were based on three topic-related standardized questionnaires / rating scales. These are the 'Nijmegen Cochlear Implant questionnaire' (NCIQ) by Hinderink, Krabbe and Van den Broek (2000:756), the 'Speech Spatial and Qualities of hearing rating scales' (SSQ) by Gatehouse and Noble (2004:85), and the 'Questionnaire on the impact of cochlear implants on QOL' (Wayman, 2001).

The impetus for designing fresh data collection instruments derived from the observation that existing instruments, including the three instruments mentioned above, displayed analogous content. A combination of the three most frequently used instruments would patently cover all the relevant areas, and while elimination of overlapping questions would avoid repetitive inquiry, the amalgamation could retain and reveal some unique questions from each original questionnaire / rating scale that would ultimately provide significant information regarding the perceived outcomes. The assumption was made that together these three topic-related questionnaires / rating scales include all the aspects necessary to gain the information needed to answer the research question. A very important



consideration in the design of the questionnaires was to identify all subjective changes (i.e. changes related to hearing ability and participation in daily activities) that bilateral cochlear implant recipients may experience. The stimulus for this consideration came from Summerfield et al. (2006) who stated that the receipt of a second implant leads to improvements in hearing, but not to significant changes in general measures of QOL. For this reason it was imperative to ensure that a holistic view was obtained of the changes after receipt of the second cochlear implant that may have an affect on the BCI user's QOL. The researcher investigated each of the three instruments and capitalized on the unique strengths of each:

- The NCIQ was specifically designed for use with adult cochlear implant users and was originally utilized in a research project designed to develop a quantifiable, self assessment, health related QOL instrument (Hinderlink, Krabbe & Van den Broek, 2000:757). Three principal domains are distinguished in the NCIQ, namely physical, psychological, and social domains, each having sub-areas. In the original study it was concluded that the internal consistency and test-retest reliability co-efficients proved to be satisfactory (Hinderlink, Krabbe & Van den Broek, 2000:757). The NCIQ also proved to be sensitive to clinical changes that are related to QOL aspects. The NCIQ (Hinderlink et al., 2000) was incorporated in the design of the current questionnaires in order to allow for detecting subjective outcomes in domains other than auditory performance.
- The 'SSQ rating scales' comprise three scales that deal with the subjective measurement of three areas, generally thought to improve with bilateral cochlear implantation (Gatehouse & Noble, 2004:85). The three areas are: speech discrimination, spatial orientation, and quality of sound. The SSQ scales are in essence three rating scales combined, viz. the 'Speech hearing rating scale', the 'Spatial rating scale' and the 'Sound quality rating scale' (Gatehouse & Noble, 2004:85). According to MED-EL, 2003, the majority of bilateral cochlear implant recipients in their studies reported benefiting from improved hearing in noise, improved hearing in quiet, restoration of spatial orientation and sound localization, and improved quality of sound. The inclusion of this scale

allowed the researcher to assess some of the benefits that have been reported by previous studies.

- Wayman (2001:54) designed a questionnaire in order to investigate the psychosocial impact of cochlear implants on the quality of life of postlingually deafened adults. In accordance with the 'International Classification of Functioning and Disability' (developed by the World Health Organization in 1999) the questionnaire was divided into six sections, namely: personal contextual factors, physical functions, communication activities, daily activities, social participation and environmental contextual factors. Wayman's (2001) findings indicated that cochlear implants can have a positive impact on all the domains investigated, which in turn exerts an influence on the QOL of postlingually deafened adults. Wayman (2001:54) recommended that the questions should ideally have been administered through an interview, which might have yielded more in-depth answers to open-ended questions than the original paper-based questionnaire.

For this reason the current study included not only a questionnaire for both the subjects with BCIs (Appendix E) and their significant other person (Appendix F), but also a semi-structured interview (Appendix D). The questionnaires were created in accordance with the guidelines suggested by Walonick (2004).

### 3.5.2 Instruments and apparatus used for objective data collection

The test battery instruments, described in Table 3.4, were used to determine the subject's audiometric outcomes objectively.

**Table 3.4: Test battery instruments used to collect objective data**

TEST BATTERY INSTRUMENT	APPLICATION
Grason-Stadler (GSI-61) Clinical Audiometer Calibrated in March 2007	This audiometer was used to determine each subject's pure tone thresholds with BCIs, speech discrimination in quiet ability, speech discrimination in noise ability, and sound localization acuity.

**Table 3.4: Test battery instruments used to collect objective data (cont.)**

<b>TEST BATTERY INSTRUMENT</b>	<b>APPLICATION</b>
Heine Mini 2000 Otoscope	This otoscope enabled the researcher to administer the otoscopic examination of the external auditory meatus and tympanic membrane.
Paper towels and Milton fluid	Paper towels and Milton fluid were used to sterilize the immittance probe tips and speculums of the otoscope before and after use.
Grason-Stadler (GSI) TympStar Calibrated in March 2007	This instrument was utilized to conduct immittance testing to detect middle ear pathology. By conducting tympanometry, valid and reliable results with regard to the subjects' middle ear functioning could be obtained. Although the CI bypasses the middle ear, the presence of middle ear pathology can influence the subject's auditory performance (Clark, 2003). The researcher had a number of different size probe tips available in order to ensure that a sufficient seal would be obtained in every case.
The 'Central Institute for the Deaf (CID): Everyday sentence list' (Davis and Silverman, 1978)	Three lists of the 'Central Institute for the Deaf (CID): Everyday sentences' (Davis & Silverman, 1978) and the translated edition in Afrikaans (Müller, nd.) were used to test the subjects' ability to discriminate speech (i.e. identify key words) at sentence level in quiet and in noise.
Monosyllabic word list for children 3-5 years (as utilised by the Department of Communication Pathology)	The Monosyllabic word list for children 3-5 years and the translated edition in Afrikaans were used to determine the subjects' ability to recognize words from a monosyllabic word list in quiet and in noise. This list was specifically chosen, instead of the adult word list, in order to save time and prevent fatigue.

### **3.6 Procedures**

This section describes the procedure used to collect the data with the different data collection instruments.

### 3.6.1 Pilot study

Pilot studies are a crucial element of a good study design. According to Teijlingen and Hundley (2001:10) the term *pilot study*, or *feasibility study*, refers to a mini version of a full-scale study, as well as to the specific pre-testing of a particular research instrument such as a questionnaire or interview schedule. Although conducting a pilot study does not guarantee success in the main study, it does increase the likelihood of successful research (Teijlingen & Hundley, 2001:10). Pilot studies fulfill a range of important functions and can provide valuable insights to other researchers. Peat, Mellis, Williams, and Xuan (2002:123) suggest specific pilot study procedures to improve the internal validity of a questionnaire. According to the authors, following these procedures determines the extent to which the study's design and the data it yields allow the researcher to draw accurate conclusions of cause-and-effect and other relationships within the data. The suggested procedures for pilot studies on questionnaires are the following:

- Administer the questionnaire to the subject/s chosen for the pilot study in exactly the same way as it will be administered in the main study;
- Ask the subjects (in the case of the current study, subjects with BCI's and their significant other persons) for feedback to identify ambiguities and difficult questions;
- Record the time taken to complete the questionnaire and decide whether it is reasonable;
- Discard all unnecessary, difficult or ambiguous questions;
- Assess whether each question provides an adequate range of responses;
- Establish whether the subjects' responses can be interpreted in terms of the information that is required;
- Check that all questions are answered and re-word or re-scale any questions that are not answered as expected and
- shorten, revise and if possible repeat the pilot study.

It was the researcher's expectation that the brief exploratory investigation of both the interview and the questionnaires for the subjects with BCIs and their 'significant other person' would contribute to the validity of the questions in the data collection instruments, and ensure the success of the questions in terms of obtaining the

information in a reasonable manner. The pilot study guided the researcher to modify the wording of some questions where the original wording could have been misleading. Conducting a pilot study prior to the main study also allowed the researcher to identify and change items which may have exposed the researcher's bias, and to replace words which were emotionally laden.

The subject for the pilot study was an adult who had BCIs, but preferred not to use them simultaneously. Although the chosen person had received BCIs six months before the day of evaluation, she still felt uncomfortable with especially the size of the second device. She was considered to be a good subject for the pilot study as she had gone through the same decision making process before obtaining a second CI, the same feelings and procedures associated with the surgery, the experience of the activation of the second CI, and in her case, a short period of binaural hearing. Because she had very limited experience with BCIs and the alleged benefits associated with the binaural implant, she did not meet the criteria for selection as a subject for this research study. As the person chosen for the pilot study was a non-user of BCIs at the time of the pilot study, the procedures of the pilot study were completed with a monaural CI only. This still allowed the researcher to pretest all the anticipated material and apparatus.

#### 3.6.1.1 Procedure for the pilot study:

The person chosen for the pilot study was contacted and asked to meet the researcher at the University of Pretoria on a mutually convenient date for the person, the person's significant other person and the researcher. Upon arrival both the person chosen for the pilot study and her significant other person were asked to read and sign a letter of informed consent (Appendix C). The researcher read through the completed background questionnaire (Appendix B) that had been sent to the person chosen for the pilot study prior to the day of evaluation. The semi-structured interview commenced. The interview was recorded and the questions were asked in an informal yet orderly manner. Once all the questions had been asked, the researcher introduced the next data collection instrument, the audiometric assessment. Procedures were conducted in the following order:

- Otoscopic evaluation

- Immittance testing
- Pure tone testing
- Speech discrimination of words in quiet
- Speech discrimination of CID sentences in quiet
- Speech discrimination of monosyllabic words in noise
- Speech discrimination of CID sentences in noise
- Localization testing.

While the researcher conducted the audiometric assessment on the person chosen for the pilot study, the significant other person was asked to complete a questionnaire (Appendix F). Once the questionnaire had been completed, the significant other person was allowed to leave the test room for a brief break. On completion of all the audiometric assessments, the person chosen for the pilot study was asked to complete a questionnaire (Appendix E) as final data collection instrument. The researcher thanked both the person chosen for the pilot study and the chosen significant other person for their time and voluntary participation.

#### 3.6.1.2 Results of the pilot study:

The entire data collection process was completed within 90 minutes. The exact time to complete each section and the few adjustments that had to be made, are discussed below.

- The semi-structured interview was completed within 20 minutes. Due to the nature of the interview (semi-structured and informal) this time period was only an indication of the approximate time such an interview might take. All the questions seemed appropriate and were well responded to with the exception of one: the person chosen for the pilot study had difficulty understanding the term 'Quality of Life'. The researcher decided to retain the term but to provide subjects who misinterpreted the question or asked for clarification, with a brief explanation of the term QOL. The reason for this was that the aim of the question was to obtain a personalized definition of the term QOL for each subject, rather than to provide the subjects with a given, fixed definition or explanation that might lead to stereotypical answers. The pilot study also led the researcher to ask the subjects in the main study to indicate the main reason

why they decided to obtain a second CI. The person chosen for the pilot study had decided to obtain a second CI in search of better speech discrimination during lectures in big classrooms. Interestingly, the person chosen for the pilot study initially experienced some of the binaural advantages associated with BCIs, but because of the size of the second device and its cosmetic appearance, she decided to cope without it.

- The audiometric assessment was completed in 40 minutes. An otoscopic evaluation was first conducted. Immittance testing, using tympanometry only, followed the otoscopic evaluation. The audiometric assessment performed on the subject during the pilot study was conducted with the subject's unilateral CI on a regular setting. Sound field thresholds were determined using sound-field measurements and both speakers on a left / right setting. The threshold at each frequency was recorded using a capital letter [S] for the sound field thresholds. The speech discrimination testing followed the sound field audiometric testing. During the speech-discrimination-in-noise test the person chosen for the pilot study complained that the signal was too loud. She reported that she perceived the sound as a twitching, aching sensation in the ear with the CI and the intensity levels were immediately reduced. The person chosen for the pilot study might have experienced loudness recruitment. Symptomatically, people with loudness recruitment often perceive 'not so loud' sounds as intolerable and are able to notice small increments in intensity. It was revealed in the semi-structured interview that the person chosen for the pilot study perceived normal kitchen sounds to be extremely loud and that she sometimes switches off her CI when a sound is intolerably loud. These subjective reports in support of the objective finding also proved the validity of including both objective and subjective measures in measuring the outcomes. It was decided to take extra caution in the main study with regard to other subjects who may experience loudness recruitment. The subjects were encouraged to indicate when sounds became uncomfortable to listen to.
- Localization acuity testing was conducted using her monaural cochlear implant only. It is commonly known that unilateral CI users experience difficulty in localizing sound sources. For this reason it was not expected that the subject

chosen for the pilot study would be able to locate the sound source accurately when it was presented from the different angles. The researcher decided to use an uncomplicated yet effectual localization test as previous studies had shown definite improvements in localization acuity. During the pilot study the researcher recognized that although the actual test seemed simple, the process of recording it could be confusing. Consequently the researcher developed an easy-to-record form for the interpretation of the localization test (Appendix G) and attached this to the subject's audiogram.

- The significant other person was asked to complete the *Questionnaire for the significant other person* (Appendix F) whilst the researcher conducted the audiometric assessment on the person chosen for the pilot study. The significant other person completed the questionnaire within 10 minutes and didn't indicate any misunderstanding of questions.
- On completion of the audiometric assessment, the person chosen for the pilot study was asked to complete the *Questionnaire for the subject with BCIs* (Appendix E). She completed the questionnaire within 20 minutes. Although some questions were difficult to answer because of her inexperience with binaural implants, the phrasing and purpose of the questions were well understood with the exception of one question. This question required the subject to report the softest sounds in her / his environment that she / he can not hear. Her answer to this was that she was unaware of the sounds that were inaudible to her for the reason that they were inaudible. This was a very relevant statement. The researcher decided to retain the question in the questionnaire, however, as it might furnish interesting responses regarding the subjects with BCIs' awareness of sounds in their environment (audible and not).

### **3.6.2 Sequencing of data collection procedure**

- The subjects were contacted by telephone and asked if they would be willing to participate in this study.
- A mutually convenient date for the data collection procedures to be conducted was decided on and the subjects' preferred language was disclosed. The



subject with BCIs and the significant other person were only required to meet the researcher once.

- A background questionnaire (Appendix B) was sent to each subject with the request that it be filled out prior to the day of evaluation. The researcher only retained and read the information provided in the background questionnaire on the day of the evaluation.
- On the arranged date, the subject and the significant other person met with the researcher at the University of Pretoria, in the foyer of the Department of Communication Pathology. Both parties were then asked to sign the letter of informed consent (Appendix C). The significant other persons, who were unable to attend on the day of evaluation, agreed that by filling out the *Questionnaire for the significant other person*, they would give their informed consent to participate in the study.
- The semi-structured interview (Appendix D) followed as soon as informed consent had been obtained. The interviews usually lasted for approximately 20 minutes.
- The evaluation of the subject with BCIs' auditory skills followed after a short break. The execution of the test battery took approximately 40 minutes to complete.
- The results of the tests in the battery were recorded on the appropriate score sheets.
- During evaluation of the subject's auditory skills the significant other person completed the *Questionnaire for the significant other person* (Appendix F). The completion of this questionnaire took approximately 10 minutes.
- On completion of the audiometric testing the subject was asked to complete the *Questionnaire for the subjects with BCIs* (Appendix E). It took approximately 20 minutes to complete this questionnaire.

### **3.6.3 Data collection procedures for the subjective data**

The following section describes all the data collection procedures used to obtain the necessary data to determine the perceived outcomes from each subject and their significant other person's perspective.

#### **3.6.3.1 Data collection procedure using a semi-structured interview**

The subjective data was partially collected by means of a semi-structured interview (Appendix D) that took place on the agreed date of evaluation. The researcher asked both closed-ended questions and open-ended questions in order to encourage the subject to express her / his thoughts, experiences and feelings related to the problem statement. All answers were recorded on the interview schedule (Appendix D). A tape recorder was also used as a back-up strategy to support the written data.

#### **3.6.3.2 The collection of data using the researcher-generated questionnaires**

On the day of the evaluation, each subject with BCIs as well as her / his significant other person was asked to complete their respective questionnaire. In total, 14 questionnaires were handed out (seven questionnaires for the seven subjects with BCIs and seven questionnaires for the seven significant other persons). Although four significant other persons could not attend the arranged date of evaluation, they agreed to fill out the *Questionnaire for the significant other person* and all 14 questionnaires were eventually returned. The data collection procedures for the subjective data using the questionnaires are listed below:

##### .1) Questionnaire for the subject with BCIs (Appendix E)

- Subjective data was further collected and verified by means of a researcher-generated questionnaire (Appendix E) that was provided to the subject with BCIs on the day of evaluation.

- The *Questionnaire for the subject with BCIs* (Appendix E) included both open-ended and closed-ended multiple option questions which involved choosing the most appropriate answer or providing a choice of a yes/no answer.
- The subject was asked not to liaise with the “significant other person” while completing the questionnaire.

#### .2) Questionnaire for the significant other person (Appendix F)

- As a means to obtain more subjective data, a significant other person of the subject with BCIs was also asked to complete a short, yet comprehensive questionnaire on the day of the evaluation. This took place at the same time that the subject with BCIs underwent audiometric testing.
- The questionnaire included both open-ended and closed-ended multiple option questions which involved choosing the most appropriate answer.
- The significant other person was asked not to liaise with the subject with BCIs or the researcher while completing the questionnaire.
- The researcher encouraged the subject to ask the researcher for clarification if a question was not fully understood.

### **3.6.4 Data collection procedure for the objective data**

A comprehensive test battery approach including an otoscopic examination, immittance testing, pure tone audiometry, speech discrimination and localization testing was used to assess the objective outcomes of each subject with BCIs. The following section describes the procedure and its implementation.

#### **3.6.4.1 Data collection procedure using the test battery approach**

An audiometric test battery is a collection of tests used to determine the degree of the hearing loss and the site of the lesion in the auditory system. Using a number of different tests allowed the audiologist to assess the subjects with BCIs’ hearing ability at different levels within the auditory system. Furthermore, the conduction of an audiometric test battery provided opportunities for ‘cross checks’. The cross

check principle in audiology was originally outlined by Jerger and Hayes in 1976. They stressed the importance of a test battery approach which means that a single test is never interpreted in isolation, but various tests are used as a cross check to verify the results of the different tests (Kent, 2004:521). A short description of each test, including its purpose and the procedure used to gain information for the evaluation of the auditory outcomes, are described below.

#### .1) Otoscopic examination

The otoscopic examination was conducted to examine the appearance and structure of the external auditory meatus and tympanic membrane (Katz, 2002:17). In this study the otoscopic examination was conducted using a Heine Mini 2000 otoscope. An otoscope is a handheld instrument that provides both illumination and magnification of the ear canal and tympanic membrane. An otoscopic examination is part of the basic adult test battery used at the PCIP and was therefore included as part of a standard procedure within the audiometric test battery. A brief description of the appearance and structure of each subject's external auditory meatus and tympanic membrane was recorded on her / his audiogram sheet.

#### .2) Immittance testing

In this study, only tympanometry was used for immittance testing. Although acoustic reflex testing is often part of immittance testing, all the subjects in this study were known to have severe-to-profound hearing loss and they were therefore not expected to have acoustic reflexes (Venter, personal communication, 2009). Tympanometry is an objective examination of middle-ear functioning. More specifically, tympanometry is a measure of the acoustic admittance in the ear canal as a function of changing ear canal pressure (Katz, 2002:169). Once a seal was obtained with an appropriate probe tip, the test could commence. The subjects with BCIs were asked to remain quiet, to relax, and to refrain from swallowing, yawning or coughing while the test was in progress. The results of the tympanometric measures were graphically displayed on a chart known as a tympanogram. The tympanogram provided information on the compliance of the subjects' middle ear system, ear canal volume, and middle ear pressure (normally equal to atmospheric pressure in healthy ears). These tympanometric measures were recorded on the

subjects' audiogram sheets and compared to normative data (Hall & Mueller, 1997). This enabled the researcher to identify abnormalities of the middle ear and Eustachian tube function, including indicators of the presence or absence of middle ear effusion and the presence of a tympanic membrane perforation (Katz, 2002:169).

### .3) Aided Sound Field Audiometry

In this study, aided sound field audiometry was used as a means to determine the lowest intensity at which the subject with BCIs can identify the presence of the signal at least 50% of the time with both cochlear implant devices switched on the regular setting. The subjects' audiometric thresholds were determined using sound field audiometry where the signal was presented from both loudspeakers on a left / right setting. The subjects were positioned with the loudspeakers located at 45° and 135° azimuth in front of the person. The subjects were informed that they were going to hear a series of tones / beeps that vary in intensity and frequency. The subjects were then instructed to press the button when a tone was heard. The subjects were also encouraged to press the button even when the tone was very faint. Frequency modulated or "warble" tones were presented at 250, 500, 1000, 2000, 3000, 4000, 6000 and 8000Hz. As a cochlear implant does not provide amplification at the 125Hz frequency, this frequency was not included (Katz, 2002). The clinical procedure used to determine the audiometric threshold at each frequency involved a down-10 dB and up-5 dB approach as was recommended by ASHA (1978 in Katz 2002:73). Testing commenced at 60 dB HL and once the subjects responded the intensity was lowered in 10dB decrements until no response was obtained. The level was then raised in 5dB increments until a response was obtained again.

The sound field audiometric test enabled the researcher to obtain objective data regarding the auditory thresholds associated with the use of BCIs. The auditory threshold at each frequency was recorded on the subject's audiogram sheet using a capital letter [S] for sound field threshold, according to international standards. Speech audiometry followed the aided sound field audiometric testing.

#### .4) Speech audiometry

Speech audiometry is an important component of the audiometric assessment for a variety of reasons. One of the most important reasons is that speech thresholds provide validating data for pure tone thresholds. Speech discrimination tests scores also provide clinicians with information on how well a person identifies words at a particular suprathreshold level (Katz, 2002:101). According to Clark (2003:708) test procedures should ultimately assess a person's ability to communicate in everyday situations. In this study, open-set speech discrimination testing where the subjects' ability to identify monosyllabic words and words in sentences at normal conversational levels, were of particular interest.

According to Katz (2002:105), when testing patients with substantial loss within a proportion of the speech frequency range (losses from 2000 to 4000 Hz or from 500 to 1500 Hz), the presentation level may be based upon a four frequency puretone average (i.e. the average of 500, 1000, 2000 and 4000Hz) instead of the SRT, so that the words can be presented at levels that ensure greater recognition. The researcher decided to take this into consideration when deciding at which intensity levels to commence the speech discrimination testing. Another important factor was to assess how well a patient can identify monosyllabic words at normal conversational levels (i.e. at 50 dB SPL) (Katz, 2002:105). Due to the versatility of speech measurements, this study made use of several speech discrimination tests to better understand how each individual's hearing loss affects her / his speech discrimination ability. The following speech discrimination tests were performed:

- Speech discrimination evaluation *in quiet* using words and sentences

The monosyllabic word list for children 3-5 years was used to determine the subjects' ability to recognize words. This list was specifically chosen, instead of the adult word list, in order to save time and to avoid causing fatigue to the person. This test was conducted with the subjects' BCIs on the regular setting and the audiometer on a left / right setting.

The subjects were informed that they were going to hear a list of words read out. The subjects were then instructed to repeat each word after it was presented. The

subjects were requested not to look at the clinicians' face during this task, as this test involved open set speech discrimination. The subjects were also encouraged to repeat as many words as possible even if they had to guess.

Testing commenced at an intensity of 50 dB HL. It was decided to commence testing at this level as 50 dB HL would provide an estimate of the subjects' speech recognition ability at a typical normal conversational level (Katz, 2002:105). A list of 10 words was presented using live voice. Depending on the subjects' score (i.e. score obtained after ten words were presented at the same intensity level), a down-10 dB and up-5 dB approach was used until a 100% score or the best score at the lowest level was obtained. The speech discrimination score (SDS) was expressed in percentage of words correctly identified and labeled excellent, good, fair, or poor (Katz, 2002:107).

The word recognition measurement enabled the researcher to determine which phonemes the subjects had difficulty with at a particular dB level. In addition to the information gained from the word recognition tests the researcher sought further information from sentence recognition scores regarding the subjects with BCIs' ability to identify key words when presented in sentences that automatically provide more contextual clues.

The speech recognition test in quiet followed the word recognition test in quiet. Three lists of the Central Institute for the Deaf (CID) everyday speech sentences (Davis & Silverman, 1978) and the Afrikaans translated version (Müller, 1987) were used to determine the subjects' ability to discriminate speech in sentences. This test was also conducted with the subjects' BCIs on the regular setting and the audiometer on a left / right setting.

Testing commenced at the lowest intensity where the subject was able to achieve a score of 100% in the speech recognition test using words. A list of 10 sentences, a total of 50 key words, was presented. The subject was required to repeat each sentence exactly as perceived. Scoring for this open set speech discrimination test was based on the number of key words correctly identified. The speech discrimination score (SDS) was expressed in percentage of words correctly identified and labeled excellent, good, fair or poor (Katz, 2002:107).

The sentence recognition measurement enabled the researcher to obtain a better approximation of how well the subjects with BCIs understand contextual material. Once the subjects' ability to discriminate speech in quiet was determined, the subjects' ability to perform the same task in the presence of interfering background noise was of interest. The speech discrimination evaluation in noise using words and sentences followed the speech discrimination evaluation in quiet testing.

- Speech discrimination evaluation *in noise* using words and sentences

Due to the challenges that cochlear implant users experience in achieving good understanding of speech in the presence of background noise, the subjects' ability to discriminate speech in the presence of competing noise was assessed. For this test the subjects with BCIs were once again required to put their BCIs on a regular setting while the audiometer was set to provide the signal and the noise simultaneously from both loudspeakers on a left / right setting. A signal to noise ratio (SNR) was pre-determined. A SNR refers to the relationship between the speech level as a function of frequency and the noise level as a function of frequency (e.g. +10 dB) (Katz, 2002:608). In this test the speech signal was presented at 60 dB SPL and the noise signal was presented simultaneously at 50 dB SPL. The subjects' ability to identify words at a SNR of 10 dB was thus determined. Both the monosyllabic word lists for children 3-5 years and three lists of the CID sentences were used to determine the subjects with BCIs' ability to discriminate speech in the presence of background noise. Given that the same word and sentence lists were used in the speech perception tests in quiet and in noise, the researcher refrained from providing any answer feedback to reduce a potential learning effect.

#### .5) Localization acuity

The final audiometric assessment was the test for localization acuity. Speech noise was used as stimulus and presented at 50dB SPL. The subjects were first positioned seated in the sound proof room with the two loudspeakers located at 45° and 135° azimuth in front of the subject approximately one meter away. The subjects were asked to listen to the sound and then indicate from where the sound was perceived by pointing to the direction or verbally responding. The sound was



presented at each loudspeaker separately (i.e. at 45° and 135°) and simultaneously / binaurally (i.e. at 45°+135°). The subjects were then asked to turn around (face the back wall of the sound proof room) in order to ‘create’ two loudspeakers behind the subjects at 225° and 315° azimuth. The sound was presented at each loudspeaker separately (i.e. at 225° and 315°) and simultaneously / binaurally (i.e. at 225°+315°). In total, the sound was presented six times. For this test the researcher created a data recording form on which the results were recorded (Appendix G).

As some studies report restored sound localization abilities with BCIs, the inclusion of this test was essential. The results from this test enabled the researcher to determine whether BCIs provide the users with localization abilities that enable them to locate sounds in space.

### **3.6.5 Data recording procedures**

In this study both qualitative and quantitative methods were utilized to collect the data. Accordingly, the data was recorded on various data recording sheets. For the objective data, audiogram sheets, and an additional form that was created for the recording of the results from the localization testing (Appendix G), were used. For the subjective data each subject was asked to record their answers on their individual questionnaires (Appendices E and F). The responses obtained in the semi structured interview were recorded by the researcher on the interview schedule (Appendix D).

### **3.6.6 Data analysis procedure**

The objective data (i.e. the results obtained in the audiometric testing) were analyzed according to standardized test norms (Hall & Mueller, 1997) and the answers to the closed ended questions from both questionnaires were analyzed using a simple scoring method. Scoring was conducted by using simple summation where each of the five possible answers provided in a multiple choice grid was given a corresponding uppercase letter, being one the first five letters of the alphabet. The multiple choice options are presented in table form in Table 3.5.

**Table 3.5: Multiple choice grids**

<b>A</b>	<b>B</b>	<b>C</b>	<b>D</b>	<b>E</b>
Never	Sometimes	Regularly	Usually	Always
Not satisfied	Fairly satisfied	No difference	Satisfied	Very satisfied
No change	Some change	Fair change	Few changes	Many changes
Negative	Slightly Negative	Neutral	Positive	Very positive
Poor	Fair	Average	Good	Excellent
Always	Usually	Regularly	Sometimes	Never
Decreased	Decreased slightly	No change	Increased Slightly	Increased

Each of the uppercase letters in the multiple choice grids, presented in Table 3.7 denotes a number / score: A = 0, B = 1, C = 2, D = 3 and E = 4. The uppercase letter 'E' denotes the highest possible number (i.e. a score of 4) and accordingly represents a significantly positive subjective outcome. The letter 'A' on the other hand denotes the lowest possible number / score (i.e. a score of 0) and represents the strongest indication for a less positive subjective outcome. The answers to the closed ended questions obtained in both questionnaires were analyzed using a simple summation scoring method. By matching the answers with the corresponding uppercase letters, the researcher was able to tally each subject's total score. The summation scoring method for the respective Questionnaires is illustrated in Table 3.6 and Table 3.7.

**Table 3.6: Summation scoring method for the questionnaire for the subjects with BCIs**

	<b>A = 0</b>	<b>B = 1</b>	<b>C = 2</b>	<b>D = 3</b>	<b>E = 4</b>	<b>Answers</b>
SECTION 1						
SECTION 2						
SECTION 3						
Total of (A to E) x						
TOTAL A's						
TOTAL B's						
TOTAL C's						
TOTAL D's						
TOTAL E's						
<b>TOTAL SCORE</b>						

Table 3.7 illustrates the summation of the answers (i.e. A to E) to the closed ended questions asked in the *Questionnaire for the significant other person* (Appendix F).

**Table 3.7: Summation scoring method for the Questionnaire for the significant other person**

	A = 0	B = 1	C = 2	D = 3	E = 4	Answers
SECTION 1						
SECTION 2						
Total of (A to E) x						
TOTAL A's						
TOTAL B's						
TOTAL C's						
TOTAL D's						
TOTAL E's						
<b>TOTAL SCORE</b>						

It was also considered important to determine the average score obtained by all the subjects. The mean of a numeric variable is calculated by adding the values of all the observations in a data set (the subjects' scores obtained in the *Questionnaire for the subject with BCIs* and the significant other persons' scores obtained in the *Questionnaire for the significant other person*) and then dividing that sum by the number of observations in the set (seven subjects with BCIs and seven significant other persons). By viewing each subject's results relative to the mean value, the subjects who achieved exceedingly outlier scores in their respective questionnaires, indicative of remarkably positive subjective outcomes, could be identified. Analysis of the subjects' performance in each of the different sections that were explored was also thought to provide significant information about the extent of the benefits achieved with regards to the different factors (i.e communication; benefits related to contextual factors; and benefits in psychosocial issues).

### 3.6.7 Data interpretation procedures

Table 3.8 illustrates the highest and lowest possible scores obtainable in both the *Questionnaire for the subject with BCIs* (Appendix E) and the *Questionnaire for the significant other person* (Appendix F). This was calculated using the simple summation scoring method. A high score (i.e. a score above the baseline value) is

indicative of significant positive subjective outcomes and a low score (i.e a score below the baseline value) indicates less favourable subjective outcomes.

**Table 3.8: Scores obtainable in the questionnaires**

QUESTIONNAIRE	TOTAL N QUESTIONS	N QUESTIONS ANALYSED BY SSM	HIGHEST POSSIBLE SCORE	BASELINE VALUE	LOWEST POSSIBLE SCORE
Questionnaire for the subject with BCIs	49	37	148 (37 questions X 4)	74	0 (37 questions X 0)
Questionnaire for the significant other person	26	19	76 (19 questions X 4)	38	0 (19 questions X 0)

Key: SSM = Simple scoring method

The answers of the remaining open-ended questions from both questionnaires and the responses obtained in the semi-structured interview were analyzed and interpreted using a qualitative method. Each subject with BCIs' subjective outcomes (i.e. scores obtained in questionnaires, responses to open-ended questions in the questionnaires and in the semi-structured interview) was viewed in light of the subject's objective outcomes obtained from the audiometric test results. This is based on the assumption that it is unlikely for a subject to reflect positive subjective outcomes if she / he does not benefit from the devices objectively. The results from both the objective and subjective data collection methods were then viewed collectively to enable the researcher to identify trends and discrepancies among BCI users, without comparing the subjects to one another.

### **3.7 Ethical Considerations**

As human beings were the focus of this investigation, it was essential to consider of the ethical implications of each aspect of the study. Ethical issues in research can be categorized into four clusters namely: protection against harm; informed consent; confidentiality and anonymity and honesty with professional colleagues (Leedy & Ormrod, 2005:101). These ethical issues correlate with the basic ethical principles described by the Yale Summer Institute (2003): respect for other persons, beneficence and non-maleficence and lastly distributive justice. The

researcher was committed to endorsing all four categories of ethical issues and the events of the research were based on the stipulated guiding principles.

In order to obtain ethical clearance a research proposal was submitted to the Research Committee of the Department Communication Pathology, as well as to the Research Proposal and Ethics Committee of the Faculty of Humanities of the University of Pretoria. The clearance for the proposal granted the researcher permission to commence with the post-graduate research study (Appendix H). Consent was obtained from the head of the Pretoria Cochlear Implant Program (Appendix A), the subjects with BCIs and their significant other persons (Appendix C).

The principle of informed consent was incorporated into the study by means of providing a letter of informed consent (Appendix C) with a brief yet comprehensive explanation of the procedures in which the subjects would be required to participate. The letters of informed consent (Appendix C) served as contracts between the researcher and the subjects in this study, in which they agreed to participate and conceded that they were allowed to withdraw from the study at any time as participation was strictly voluntary (Leedy & Ormrod, 2005:101). As some significant other people were unable to attend, they agreed that by filling out and submitting the questionnaire, they granted informed consent. To ensure confidentiality, an active attempt was made to remove any element that might indicate the subjects' identities. Throughout this study a numbering system was used rather than using the subjects' actual names, as a means to assure privacy. The subjects were informed that the results / findings of the study would be published in the form of a dissertation and a research article. The subjects were also informed that all research data will be archived for 15 years.

### **3.8 Validity and reliability**

According to Leedy and Ormrod (2005:28), the validity of a measurement is the extent to which the instrument measures what it is supposed to measure. Reliability is the consistency with which a measuring instrument yields a certain result when the entity being measured has not changed. It is the researcher's opinion that both the validity and reliability in this study were enhanced by using an appropriately

compiled questionnaire for not only the subjects with BCIs (Appendix E) but also their significant other persons (Appendix F). Furthermore, the pilot study that preceded the main study enabled the researcher to determine the feasibility of the study, which enhanced the validity and reliability of the study (Leedy & Ormrod, 2005:110).

The comparison of the different results (i.e. objective and subjective data, through formal audiometric assessments and questionnaires) and responses from two different persons (the subject with BCIs and her / his significant other person) further enhanced the validity and reliability of this study. This also ensured that triangulation of results could occur. Triangulation commonly occurs in mixed method designs and is often used by researchers in comparing multiple data-sources in search of common themes to support the validity of their findings (Leedy & Ormrod, 2005:100). In this study, triangulation allowed for the multiple data collection material to converge and support both the objective and subjective outcomes of adults with BCIs.

### **3.9 Conclusion to Chapter three**

In this chapter, the methodology used to conduct this study is set out in detail. The chosen method, utilizing a combination of objective and subjective data collection materials, proved to be effective in obtaining the data. The semi-structured interview (Appendix D) and two questionnaires, one for the subject with BCIs (Appendix E) and one for a significant other person (Appendix F), enabled the researcher to obtain a holistic understanding of each BCI user's subjective outcomes. The comprehensive audiometric test battery, with the addition of a localization test, was effective in the evaluation of the objective outcomes. Furthermore, the use of both quantitative and qualitative measures to analyze and interpret the data provided for triangulation. Lastly, this method allowed for the results from the various assessments to converge and ultimately provide an answer to the research question.

### **3.10 Summary**

The method used to accomplish the aims set for this research project, proved to be sufficient. All the necessary data was collected through the diligent application of the chosen research design and competent use of both quantitative and qualitative measures in determining the outcomes. The combination of approaches used, allowed the researcher to accurately determine and assess the outcomes of each BCI user in the PCIP.

## **CHAPTER 4**

### **A DISCUSSION OF THE RESULTS**

In Chapter 4, the collected and analysed data are discussed in detail. The results are presented according to the sub-aims of this study and where appropriate, displayed visually using graphic forms including tables and figures. The findings are also considered from the perspective of prior research and existing literature. Significant findings are clearly illustrated and supported by an interpretation of the specific finding in each case.

#### **4.1 Introduction**

In order to obtain specific data, five sub-aims were formulated that enabled the researcher to accomplish the main aim of this study. In an attempt to achieve the sub-aims, the researcher used several data collection instruments and appliances. Due to the extensiveness of the data collection procedures used, the results are discussed in accordance with the sub-aims, as described in the methodology section of this study.

Under each sub-aim, the rationale for the inclusion of that specific sub-aim is first explained. This exposition is followed by a presentation of each of the subjects' results related to that specific sub-aim. The individual results of each subject are typically displayed in table form, followed by a holistic interpretation and clarification of the findings using scientific explanations. Where appropriate, visual illustrations of the results using graphic presentations, are provided. Throughout this study and especially in this chapter, a numbering system is used to refer to the individual subjects as a means to assure privacy.

Table 4.1 displays a brief case history of each of the subjects with BCIs who participated in this study. Information is provided about the onset and nature of each subject's hearing loss, use of hearing aid amplification, age at which the subject received his / her first and second cochlear implant, as well as the subject's experience in binaural hearing. This allows the reader to become acquainted with each subject's history of hearing loss, amplification and bilateral listening



experience, which may assist the reader in appreciating the the individual findings related to the sub-aims.

**Table 4.1 Case history of the subjects with BCIs**

SUBJECTS	CASE HISTORY
S=1	S=1 had a history of an acquired hearing loss following meningitis. She received her first CI in her left ear at a young age of 33 months and the second CI at age 16. By the time this study took place, S=1 had almost two years experience with BCIs. S=1 did not benefit from conventional hearing aids (HAs) and therefore chose not to use a hearing aid (HA) in the contra-lateral ear before receiving the second CI.
S=2	S=2 had an idiosyncratic hearing loss that started during childhood following several courses of antibiotics and a high dosage of penicillin. The first CI was obtained at age 45 in her left ear and the second CI six years later. By the time the study took place, S=2 had two years experience with BCIs.
S=3	S=3 had a family history of hearing problems and experienced a progressive hearing loss. At the age of 45 his hearing sensitivity had decreased dramatically and he received his first CI in his right ear. Nine years later, he received his second CI and by the time this study took place, he had one year experience with BCIs.
S=4	S=4 had a history of a congenital bilateral hearing loss and use of hearing aid amplification. Due to the progressive nature of his hearing loss, his hearing sensitivity gradually reduced to a point where he no longer benefited from wearing hearing aids. He received his first CI at age 20 in his left ear and the second CI six years later. Before receiving the second CI, he made use of bimodal amplification for one year. By the time this study took place, he had one year experience of binaural hearing with BCIs.
S=5	S=5 had a history of a sudden idiosyncratic acquired hearing loss at age 20. She received her first CI in her left ear two years after identification of her SNHL at the age of 22 and the second CI eight years later. By the time this study took place, she had one year experience with BCIs.

**Table 4.1 Case history of the subjects with BCIs (continued)**

SUBJECTS	CASE HISTORY
S=6	S=6 had a history of middle ear pathology during childhood and was first diagnosed with a hearing loss at the age of 5. The nature of the hearing loss was progressive and after many years of strenuous trials with HA amplification and other compensatory strategies she only received her first CI in her right ear at an age of 50+. Three years later she received the second CI. By the time this study took place she had two years experience with BCIs.
S=7	S=7 had a history of congenital hearing loss. She used hearing aid amplification from an early age and received her first CI in her left ear when she turned eight. Almost ten years later, at age 18, she received the second CI. Before receiving the second CI, S=7 continued to make use of HA amplification in the non-implanted ear. By the time the study took place S=7 had one year experience of binaural hearing with BCIs.

It is evident from Table 4.1 that the subjects had very unique and diverse histories with regard to the onset and nature of their hearing loss, the use of HA amplification prior to receiving their second CI, and the extent of their experience in binaural hearing. The majority of the adults (N=5) at the PCIP had a postlingual onset of deafness and all the subjects had at least one year experience with BCIs at the time this study commenced. Given that the subjects with BCIs had diverse case histories, the smaller sample size enabled the current researcher to present each of the subject's results individually and discuss the results holistically in accordance with the sub-aims.

#### **4.2. SUB-AIM 1: The objective auditory outcomes of subjects with BCIs**

The rationale for the inclusion of this sub-aim derived from previous research on BCIs which generally found BCI-users to have enhanced binaural auditory skills in speech discrimination and spatial orientation (Cochlear, 2005; Gautschi, 2003; Gouws, 2005; Litovsky et al., 2004; Litovsky, et al., 2006; Tyler et al., 2002; Tyler et al., 2006; MED-EL, 2003). Despite the positive pattern that had emerged from previous research, some differences in auditory performance among BCI-users

were unanswered for. As various studies used disparate procedures to determine the audiometric benefits of BCIs, the differences in performances were difficult to predict.

The current researcher realized that ideally, the objective auditory outcomes of every recipient of BCIs should be assessed. The assessment of the audiometric benefits of BCI recipients within every cochlear implant program can not only enhance the validity of that program's policy to use BCIs as authentic intervention for people with severe-to-profound hearing loss, but also guarantee evidence-based practice. The current researcher also assumed that the objective auditory outcomes of the subjects with BCIs would be prerequisite to understanding the subjects' self-reported subjective outcomes that were also of interest in this study.

The following tests were included in the audiometric test battery used to determine the objective auditory outcomes of the subjects with BCIs: otoscopic examination; immittance testing; aided sound field audiometry; speech discrimination testing; and aided localization testing. A discussion of the results obtained in each audiometric test is provided.

#### 4.2.1. Otosopic examination

The otoscopic examination was conducted to examine the appearance and structure of the external auditory meatus or ear canal and tympanic membrane (Katz, 2002:17). The otoscopic examination revealed no cerumen impaction in any of the subjects' ear canals and all seven of the subjects' tympanic membranes appeared semitranslucent, pearly gray and slightly concave. These findings were indicative of normal ear canals and tympanic membranes (Katz, 2002:17).

#### 4.2.2 Immittance testing

In this study tympanometry was exclusively used for immittance testing. Six subjects obtained Type A tympanograms bilaterally. Type A tympanograms are indicative of normal pressure in the middle ear with normal mobility of the middle ear system which includes the tympanic membrane and the conduction bones. These results confirmed the results obtained in the otoscopic examination and indicated normal middle ear and Eustachian tube functioning, excluding the

presence of middle ear effusion and the presence of a tympanic membrane perforation (Katz, 2002:169).

Subject five (S=5) obtained a normal Type A tympanogram in the left ear but a divergent Type Ad tympanogram in the right ear. Although it was originally proposed that any subject with a tympanogram other than a Type A would be referred to an Ear, Nose and Throat specialist and excluded from the study until a Type A tympanogram was evident, the nature of the subject's abnormal tympanogram was permanent as S=5 had middle-ear surgery eight years prior to the year this study commenced. It was agreed that the tympanogram was unlikely to change over time or have an influence on the succeeding test results. The decision was therefore taken to continue with testing on the same day as was originally scheduled.

#### 4.2.3 Aided Sound Field Audiometry

Aided sound field audiometry was conducted to obtain audiometric thresholds using frequency modulated or warble tones in the sound field with both cochlear implants switched on and at the regular setting. Table 4.2 illustrates the results of the puretone testing and provides the subjects' puretone thresholds based upon a three frequency puretone average (i.e. the average of 500, 1000 and 2000 Hertz). The results depict each subject with BCIs' current performance with two cochlear implants and do not constitute a comparison with the subject's performance with one CI.

**Table 4.2: Results of the aided sound field audiometric testing**

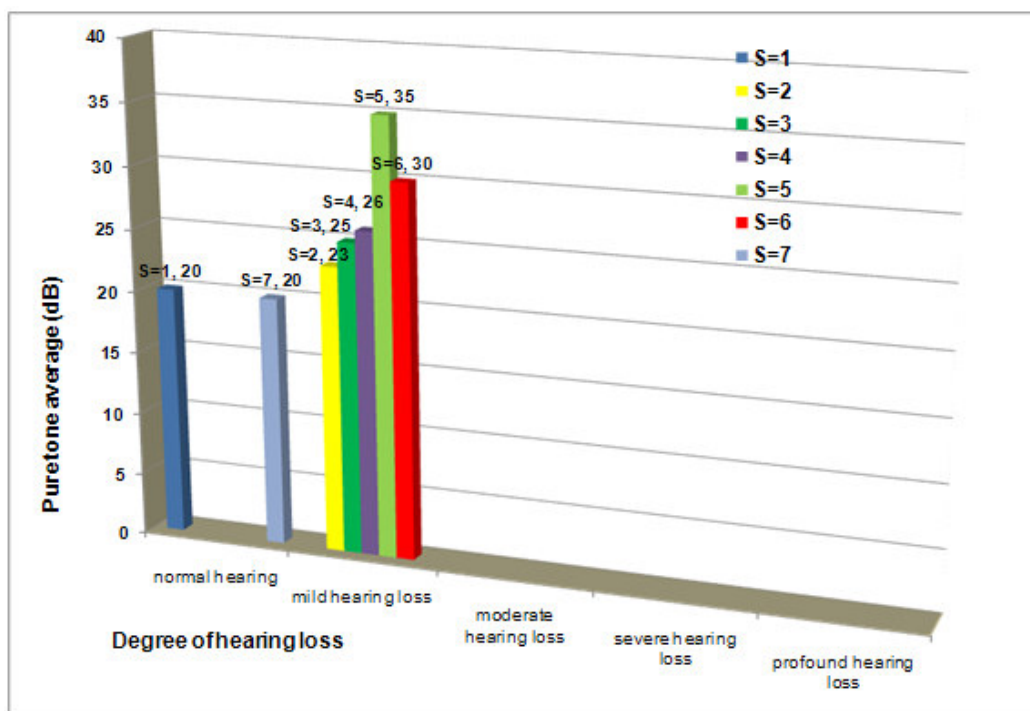
SUBJECT	PURETONE RESULTS WITH BCIs
S=1	S=1 obtained an average puretone threshold of 20 dB HL which is indicative of normal hearing in an adult. The overall slope of this subject's audiogram pointed to a mild high frequency hearing loss (Jerger, 1980, in Hall & Mueller, 1997:104).
S=2	S=2 obtained an average puretone threshold of 23 dB HL which is indicative of mild hearing loss in an adult. The entire slope of this subject's audiogram, throughout the full frequency spectrum, pointed to a mild high frequency

**Table 4.2: Results of the aided sound field audiometric testing (continued)**

SUBJECT	PURETONE RESULTS WITH BCIs
S=2	hearing loss. No threshold was obtained at 8000Hz as the intensity of the stimulus exceeded the audiometer's capacity at that frequency (Jerger, 1980, in Hall & Mueller, 1997:104). According to Venter (2009, personal communication) CIs often do not stimulate sound at frequencies exceeding 6000Hz.
S=3	S=3 obtained an average puretone threshold of 25 dB HL which is indicative of mild hearing loss in an adult. The entire slope of this subject's audiogram demonstrated the presence of a mild-to-moderate high frequency hearing loss (Jerger, 1980, in Hall & Mueller, 1997:104).
S=4	S=4 obtained an average puretone threshold of 26 dB HL which is indicative of mild hearing loss in an adult. The entire slope of this subject's audiogram indicated a mild high frequency hearing loss (Jerger, 1980, in Hall & Mueller, 1997:104).
S=5	S=5 obtained an average puretone threshold of 35 dB HL which is indicative of mild hearing loss in an adult. The entire slope of this subject's audiogram reflects a relatively flat mild hearing loss with a gradual rise in the higher frequencies (Jerger, 1980, in Hall & Mueller, 1997:104).
S=6	S=6 obtained an average puretone threshold of 30 dB HL which is indicative of mild hearing loss in an adult. The entire slope of this subject's audiogram pointed to a relatively flat mild hearing loss throughout the entire high frequency spectrum with a sudden decrease at 8000Hz (Jerger, 1980, in Hall & Mueller, 1997:104).
S=7	S=7 obtained an average pure-tone threshold of 20 dB HL which is indicative of normal hearing in an adult. The entire slope of this subject's audiogram indicates a relatively flat mild hearing loss throughout the entire high frequency spectrum with a sudden decrease at 8000Hz (Jerger, 1980, in Hall & Mueller, 1997:104).

As presented in Table 4.2, the most significant objective result shared by all seven subjects was a degree of hearing loss with BCIs, although the range varied. Two subjects achieved puretone averages of 20 dB HL which, according to Jerger

(1980, in Hall & Mueller, 1997:104), is indicative of normal hearing in an adult. The remaining five subjects with BCIs obtained average puretone thresholds between 21 and 40 dB HL which, according to Jerger (1980, in Hall & Mueller, 1997:104), is indicative of a mild hearing loss. Considering the subjects' degree of hearing loss without amplification or prior to receiving their first cochlear implant, viz. severe-to-profound hearing loss, a mild hearing loss is indicative of improved hearing sensitivity with BCIs and thus indicative of a significant objective outcome with BCIs. The subjects with BCIs' aided puretone averages are illustrated in Figure 4.1.



**Figure 4.1: Aided puretone averages**

Figure 4.1 clearly illustrates that two subjects obtained normal hearing and five subjects obtained puretone thresholds at levels indicative of a mild hearing loss. The puretone threshold was based upon a three frequency puretone average (i.e. the average of 500, 1000 and 2000). A mild high frequency loss was evident in six of the subjects when the entire configuration of their audiograms across the full frequency spectrum was taken into account. When compared to the subjects' audiograms prior to receiving their first cochlear implant, their current auditory thresholds with BCIs showed a significant objective outcome. Since all the subjects' puretone averages had improved with BCIs, which is regarded an important

indicator of improved hearing sensitivity, the subjects' performance in the speech discrimination testing were also found to reveal remarkable results.

#### 4.2.4 Speech discrimination testing

The subjects with BCIs' ability to discriminate speech (monosyllabic words and sentences), in quiet and in noise, was assessed. The speech discrimination test in noise was especially important, as background noise in a room can compromise speech discrimination by masking the acoustic and linguistic cues in a message. For individuals with hearing loss, the challenges of separating the speech signal from the competing background noise to be able to understand speech becomes even more complicated.

According to Katz (2002:608) the most important factor for accurate speech discrimination is not the overall background noise, but rather the relationship between the speech level as a function of frequency and the noise level. This relationship is referred to as the signal to noise ratio (SNR). Although the SNR required by individuals with hearing loss varies with the degree of sensory neural hearing loss (SNHL), it has been found that individuals with a SNHL require a +4 to +12 dB SNR to obtain scores comparable to the scores of listeners with normal hearing (Katz, 2002:608). Evidently, speech discrimination in adults with normal hearing is not severely reduced until the SNR reaches 0 dB (Katz, 2002:608).

In this study, the subjects' ability to discriminate speech in the presence of noise was determined at a pre-selected SNR of +10 dB, where the speech signal was presented at 60 dB SPL and the noise level at 50 dB SPL, simultaneously. These levels were specifically chosen to enable the researcher to determine the subjects' ability to discriminate speech in noise at that particular SNR while the speech signal is presented at a level slightly above a typical conversational level (Katz, 2002:105). The subjects' speech discrimination scores (SDS) in each of the speech discrimination tests were expressed in the percentage of words correctly identified and the scores were labeled as 'excellent', 'good', 'fair', or 'poor'. In this study, a SDS of 0-25% was labeled 'poor', a SDS of 26-50% was labeled 'fair', a SDS of 51-75% was labeled 'good', and a SDS of 76-100% was labeled 'excellent'. The

results of the speech discrimination tests using words in quiet and in the presence of noise are presented in Table 4.3 below.

**Table 4.3: Results of the speech discrimination tests using words**

Speech discrimination <i>in quiet</i> using Monosyllabic words.	Speech discrimination <i>in noise</i> using Monosyllabic words.
S=1 obtained a maximum SDS of 100% at 40 dB SPL.	S=1 identified 80% of the words at a 60 dB signal while competing noise was presented at 50 dB, a SNR of +10 dB.
S=2 obtained a maximum SDS of 100% at 50 dB SPL.	S=2 identified 50% of the words at a 60 dB signal while competing noise was presented at 45 dB, a SNR of +15 dB.
S=3 obtained a maximum SDS of 100% at 45 dB SPL. Interestingly, at 50 dB, S=3 was only able to repeat 60% of the words. *roll-over.	S=3 identified 70% of the words at a 60 dB signal while competing noise was presented at 45 dB, a SNR of +15 dB.
S=4 obtained a maximum SDS of 100% at 45 dB SPL.	S=4 identified 40% of the words at a 60 dB signal while competing noise was presented at 45 dB, a SNR of +15 dB.
S=5 obtained a maximum SDS of 100% at 40 dB SPL.	S=5 identified 90% of the words at a 60 dB signal while competing noise was presented at 50 dB, a SNR of +10 dB.
S=6 obtained a maximum SDS of 100% at 45 dB SPL.	S=6 identified 40% of the words at a 60 dB signal while competing noise was presented at 45 dB, a SNR of +15 dB.
S=7 obtained a maximum SDS of 100% at 55 dB SPL.	S=7 identified 60% of the words at a 60 dB signal while competing noise was presented at 50 dB, a SNR of +10 dB.

\*A rollover is representative of individuals with retro-cochlear auditory dysfunction (Hall & Mueller, 1997:147).

The findings in the speech discrimination test using words in quiet revealed that all seven subjects were able to obtain a maximum SDS of 100%. According to Katz (2002:755) open set speech discrimination scores obtained by postlingually



deafened adults with CIs vary greatly from individual to individual but with recent devices, most patients obtain scores in the 30 to 40% correct range on monosyllabic word tests. The finding that all the subjects were able to obtain a maximum SDS of 100% suggests that unilateral cochlear implant users are likely to achieve at least improved speech discrimination scores of words in quiet with BCIs.

The subjects' ability to discriminate words when presented at a 60 dB SPL while competing noise was simultaneously presented at a 50 dB SPL was also determined. Two subjects obtained 'excellent' SDS, another two subjects obtained 'good' SDS and the remaining three subjects obtained 'fair' SDS. As can be seen from Table 4.3, three subjects were able to discriminate speech at the pre-selected intensity levels at a SNR of +10dB. According to Katz (2003:608) the SNR required by individuals with hearing loss varies with the degree of SNHL. Individuals with a SNHL require +4 to +12 dB SNRs to obtain scores comparable to the scores of listeners with normal hearing. The two subjects (S=1 & S=7) who obtained puretone thresholds at levels indicative of normal hearing were able to discriminate 80% and 60% respectively at a +10 dB SNR. This is indicative of a significant objective outcome with BCIs.

The majority of the subjects (N=4) experienced discomfort and a reduced ability to discriminate between words at the pre-selected intensity levels and asked that the noise level be reduced. The researcher complied with the subjects' request and reduced the noise level to 45 dB SPL. These four subjects were able to discriminate words in noise at a SNR of +15 dB. The researcher predicted that some subjects may experience loudness recruitment. The phenomenon of loudness recruitment is the psychoacoustic expression of the loss of a large component of outer hair cells and the concurrent preservation of a large component of inner hair cells and type one cochlear neurons (Hall & Mueller, 1997:244). This caused some subjects with SNHL to perceive a disproportionate increase in the sensation of loudness in response to a relatively slight increase in the intensity of an acoustic signal. Another important consideration is that although the sound may be well within the CI user's C-levels, it is possible for the subject to perceptually perceive the sound as too loud through the CI. C-levels refer to the 'loud but comfortable' listening levels for the cochlear implant user at the individual

electrodes (Katz, 2002:753). The current researcher predicted that sentence recognition scores would provide further information regarding the subjects with BCIs' ability to identify key words when presented in sentences that automatically provide contextual clues. The results from the speech discrimination tests using sentences in quiet and in the presence of noise are presented in Table 4.4.

**Table 4.4 Results of the speech discrimination tests using sentences**

Speech discrimination <i>in quiet</i> using CID sentences.	Speech discrimination <i>in noise</i> using CID sentences.
S=1 obtained a maximum SDS of 100% (i.e. a score of 50/50) at 35 dB SPL.	S=1 obtained a SDS of 47/50, a percentage of 94% when CID sentences were presented at a 60 dB signal while competing noise was presented at 50 dB.
S=2 obtained a maximum SDS of 100% (i.e. a score of 50/50) at 35 dB SPL.	S=2 obtained a SDS of 41/50, a percentage of 82% when CID sentences were presented at a 60 dB signal while competing noise was presented at 45 dB.
S=3 obtained a maximum SDS of 100% (i.e. a score of 50/50) at 40 dB SPL.	S=3 obtained a SDS of 48/50, a percentage of 96% when CID sentences were presented at a 60 dB signal while competing noise was presented at 45 dB.
S=4 obtained a maximum SDS of 100% (i.e. a score of 50/50) at 50 dB SPL.	S=4 obtained a SDS of 44/50, a percentage of 88% when CID sentences were presented at a 60 dB signal while competing noise was presented at 45 dB.
S=5 obtained a maximum SDS of 100% (i.e. a score of 50/50) at 40 dB SPL.	S=5 obtained a SDS of 50/50, a percentage of 100% when CID sentences were presented at a 60 dB signal while competing noise was presented at 50 dB.
S=6 obtained a maximum SDS of 100% (i.e. a score of 50/50) at 45 dB SPL.	S=6 obtained a SDS of 49/50, a percentage of 98% when CID sentences were presented at a 60 dB signal while competing noise was presented at 45 dB.

**Table 4.4 Results of the speech discrimination tests using sentences**

Speech discrimination <i>in quiet</i> using CID sentences.	Speech discrimination <i>in noise</i> using CID sentences.
S=7 obtained a maximum SDS of 100% (i.e. a score of 50/50) at 55 dB SPL	S=7 obtained a SDS of 45/50, a percentage of 90% when CID sentences were presented at a 60 dB signal while competing noise was presented at 50 dB.

In accordance with the word recognition scores, all the subjects with BCIs were able to recognize 100% of the key words when these words were presented in sentences. Considering that postlingually deafened adults with unilateral cochlear implants can obtain scores in the 70 to 80% correct range on open set sentence tests (Katz, 2002:755), the scores obtained in the speech discrimination test using sentences in quiet suggest that with BCIs, cochlear implant users can achieve improved speech discrimination ability.

The sentence recognition in noise test established the subjects' discrimination scores at the same SNRs as was used in the word recognition in noise test. All the subjects obtained 'excellent' SDS, a score between 76 and 100%. All the subjects obtained a SDS in the sentence recognition in noise test that was higher (when expressed in percentage correct) than their SDS in the word recognition in noise test. The researcher anticipated this finding as the sentences provided the subjects with contextual material, in that the key words were preceded and followed by other words in the sentence that automatically provided contextual clues as to what the key words might be.

Overall, the results from the speech discrimination testing in this study provide evidence that BCI-users can discriminate speech in quiet and in the presence of interfering background noise. The results demonstrate the subjects' ability to segregate speech from background sounds and their ability to monitor more than one ongoing important source of information. According to Litovsky (2008:4) when both ears are implanted, speech intelligibility in noise can improve dramatically compared with unilateral listening. Litovsky (2008:4) explains that many complex factors contribute to the ability to separate speech signals from background noise

including the characteristics of the signal and masker, the degree of the subjects' hearing loss, and the subjects' gain in the three primary effects related to binaural hearing.

The factors mentioned by Litovsky (2008:4), that could contribute to a BCI-users' ability to segregate speech from noise, could explain some of the current study's findings. In the current study all the subjects with BCIs' auditory thresholds had improved with bilateral cochlear implants versus their hearing sensitivity prior to receiving their first cochlear implant. This resulted in increased perceptual loudness which, as explained by Litovsky (2008:4), can contribute to the subjects' ability to perform speech recognition in noise tasks.

Given that all the subjects who participated in the audiometric testing had BCIs, all the subjects could selectively attend to the ear with the more favourable SNR to maximize their speech recognition performance, a characteristic feature of the head shadow effect (Litovsky, 2008:4). Another component of binaural hearing that may have contributed to the subjects' ability to separate the speech from the noise signal was the binaural squelch effect. According to Litovsky (2008:4), in BCI users the auditory system can combine information to form a better central representation than that which is available with only monaural input. Similar findings have been reported in various other studies (Van Hoesel & Tyler, 2003; Schleich, Nopp & D'Haese, 2004). It was also important to consider that the subjects' improved ability to discriminate speech in noise could be related to improvements in localization acuity, for example subtle changes in the subjects' subconscious head positioning, an adeptness important for speech discrimination. The subjects with BCIs' ability to localize sounds in space were subsequently investigated.

#### 4.2.5 Localization testing

Localization testing in both the frontal and posterior hemi-field was of interest in this study and followed the speech discrimination in noise assessment. Previous studies on BCIs found enhanced localization acuity, and some found restored spatial separation (MED-EL, 2003, accessed May 22, 2007). Tyler et al. (2006:113) found that patients with BCIs typically have better localization skills when using both implants than when using one implant. Despite these findings, Tyler et al.

(2006:113) concluded that localization acuity is still inferior to that of listeners with normal hearing. To determine the subjects with BCIs' ability to localize a sound source in a sound proof room, speech noise was presented at 50 dB SPL from six locations throughout the full 360° of azimuth in the horizontal plane through the interaural axis (Cochlear Limited, 2005, accessed February 14, 2007). The subjects were asked to listen to the sound and then indicate from where the sound was perceived by pointing to the direction or verbally responding. The sound was presented at each loudspeaker separately (i.e. at 45° and 135°) and simultaneously / binaurally (i.e. at 45°+135°). The subjects were then asked to turn around (face the back wall of the sound proof room) in order to 'create' two loudspeakers behind the subjects at 225° and 315° azimuth. The sound was presented at each loudspeaker separately (i.e. at 225° and 315°) and simultaneously / binaurally (i.e. at 225°+315°). In total, the sound was presented six times. Table 4.5 illustrates the results of the localization test.

**Table 4.5: Results of the localization test**

SUBJECT	RESULTS WITH BCIs
S=1	<ul style="list-style-type: none"> <li>▪ S=1 was able to localize the sound source at 45°, 135°, 225° and 315° azimuth, when separately presented at an intensity level of 50dB SPL. S=1 was unable to localize the sound source when presented simultaneously / binaurally from the front at 45°+135° azimuth and from behind at 225°+315° azimuth. When presented from the front at 45°+135° azimuth simultaneously, S=1 wrongly indicated that the sound originated from the left. When presented from the back at 225°+315° azimuth simultaneously S=1 indicated that the sound was once again perceived from the left. S=1's left ear was implanted first.</li> </ul>
S=2	<ul style="list-style-type: none"> <li>▪ S=2 obtained similar results to S=1. S=2 was able to localize the sound source at 45°, 135°, 225° and 315°, when separately presented at an intensity level of 50dB SPL. When presented from the front at 45°+135° azimuth simultaneously, S=2 wrongly indicated that the sound originated from the left. When presented from the back at 225°+315° azimuth simultaneously, S=2 indicated that the sound was once again perceived from the left. S=2 received the first cochlear implant in the left ear.</li> </ul>

**Table 4.5 Results of the localization test (continued)**

SUBJECT	RESULTS WITH BCIs
S=3	<ul style="list-style-type: none"> <li>▪ S=3 was able to localize the sound source at 45°, 135°, 225° and 315° azimuth, when separately presented at an intensity level of 50dB SPL.</li> </ul>
S=4	<ul style="list-style-type: none"> <li>▪ S=3 was also able to localize the sound source when presented binaurally at 45°+135° and 225°+315° azimuth simultaneously by verbally responding: “I hear it above me”.</li> </ul>
S=5	<ul style="list-style-type: none"> <li>▪ S=4 was able to localize the sound source at 45°, 135°, 225° and 315° azimuth, when separately presented at an intensity level of 50dB SPL.</li> </ul>
S=5	<ul style="list-style-type: none"> <li>▪ S=4 was also able to localize the sound source when presented binaurally from the front at 45°+135° azimuth simultaneously, but indicated that he perceived the sound from the right when it was presented binaurally at 225°+315° azimuth simultaneously. S=4 received the first implant in the left ear.</li> </ul>
S=6	<ul style="list-style-type: none"> <li>▪ S=5 was able to localize the sound source at 45°, 135°, 225° and 315° azimuth, when separately presented at an intensity level of 50dB SPL.</li> </ul>
S=6	<ul style="list-style-type: none"> <li>▪ S=5 was also able to localize the sound source when presented binaurally from the front at 45°+135° azimuth simultaneously. When presented binaurally at 225°+315° azimuth simultaneously, S=5 indicated the sound originated from the right. S=5 received her first cochlear implant in the left ear.</li> </ul>
S=7	<ul style="list-style-type: none"> <li>▪ S=6 was able to localize the sound source at 45°, 135°, 225° and 315° azimuth, when separately presented at an intensity level of 50dB SPL.</li> </ul>
S=7	<ul style="list-style-type: none"> <li>▪ S=6 was also able to localize the sound source when presented binaurally from the front at 45°+135° azimuth simultaneously and from behind at 225°+315° simultaneously.</li> </ul>
S=7	<ul style="list-style-type: none"> <li>▪ S=7 was able to localize the sound source at 45°, 135°, 225° and 315° azimuth, when separately presented at an intensity level of 50dB SPL.</li> </ul>
S=7	<ul style="list-style-type: none"> <li>▪ S=7 was also able to localize the sound source when presented binaurally from the front at 45°+135 azimuth simultaneously but wrongly indicated that the sound originated from the right when the sound was presented at 225°+ 315° azimuth simultaneously. S=7 received her first cochlear implant in her left ear.</li> </ul>

All the subjects in this study were able to localize sounds presented separately at four different locations throughout the full 360° of azimuth in the horizontal plane through the inter-aural axis. The majority of the subjects (N=5) were also able to localize the sound source when presented simultaneously from the front i.e. binaurally at 45°+135° and fewer subjects (N=2) were able to localize the sound source when presented simultaneously from behind i.e. binaurally at 225°+315° azimuth. These two subjects reported verbally that they perceived the sound to be coming from all directions. The subjects who were unable to localize the sound source when presented binaurally indicated that they perceived the sound from the left or the right. This was not related to the ear that was implanted first.

The ability to localize sounds when presented from six different angles in the full 360 degrees azimuth was revealed. Although all the subjects with BCIs were able to localize the sound source from the frontal and posterior hemi-field when the sound was presented separately, only two subjects were able to localize sounds when presented binaurally / simultaneously from the front and from behind.

The reason for most subjects' inability to localize the sound source when presented binaurally may suggest that some subjects in this study do not yet benefit from inter-aural timing differences with the current arrangement of separately programmed speech processors (Peters, 2006:3). It is important to bear in mind that in normal hearing listeners, binaural hearing depends on the cues of inter-aural amplitude differences (IADs), i.e. differences between the ears in intensity of sounds, and inter-aural timing differences (ITDs), i.e. differences in arrival time between the two ears (Rubinstein, 2004:446). These binaural cues provide the listener with robust information about the direction of sound sources and provide powerful 'tools' for listening in complex environments (Litovsky et al., 2004:653).

In real life conditions, different sounds at various intensities may originate from different angles in a complex listening environment. Therefore, the objective localization test used in the current study was considered a reliable simulation of a person's ability to localize sound in a quiet and controlled listening environment. The findings correlated with those of numerous other studies where it was found that BCIs provide users with an improved ability to localize the source of sound.

Although most studies concur that 'directional hearing' is a listener's ability to localize sound sources in 'space', fewer studies included the full 360 degrees of azimuth in their localization testing (Tyler, 2002; Litovsky, 2006). In a study conducted by MED-EL (2003, accessed May 22, 2007) the researchers concluded that BCIs successfully restore sound localization. The researchers found that bilateral cochlear implant users can localize sound sources in the frontal horizontal plane with an average deviation in the order of 15 degrees. Since listeners with normal hearing can tell where sound is coming from in the horizontal plane (at ear level) with an accuracy of approximately 14 degrees (Pijl, 1991:431), MED-EL (2003, accessed May 22, 2007) reported that sound localization is restored with BCIs. Inspection of the localization test conducted in that study revealed that only the frontal hemi-field was included in their test array (MED-EL, 2003, accessed May 22, 2007) which may disallow such a generalized statement.

Although all the subjects in the current study were able to localize the source of the sounds when presented from four different angles, the researcher was reluctant to state that spatial separation had been restored. This reluctance was based on the majority of the subjects' inability to localize sounds when presented binaurally, as well as the fact that the test only assessed the subjects' ability to localize speech noise presented at the same intensity from six different locations.

#### 4.2.6 Review of sub-aim 1

The auditory benefits gained from BCIs have been investigated and documented in the past. It is generally acknowledged that the use of BCIs improve hearing in quiet and in noise, improve spatial orientation and sound localization, and can provide recipients with better quality of sound (Litovsky, et al., 2006; Litovsky et al., 2004; Tyler et al., 2006; Tyler et al., 2002; Gouws, 2005; Gautschi, 2003; Cochlear, 2005; MED-EL, 2003). As was anticipated, the results from the audiometric tests showed that the majority of the subjects with BCIs were able to achieve the mentioned benefits which were indicative of significant objective auditory outcomes with BCIs. The results indicated that all the subjects obtained enhanced binaural auditory skills in hearing sensitivity, speech discrimination in quiet and in noise, and to some extent in localization acuity.



Despite the significant objective outcomes, the researcher needed to establish whether the subjects could subjectively experience the benefits evinced by the objective measurements, in everyday listening situations. The second sub-aim explored the self-reported subjective outcomes of subjects with BCIs.

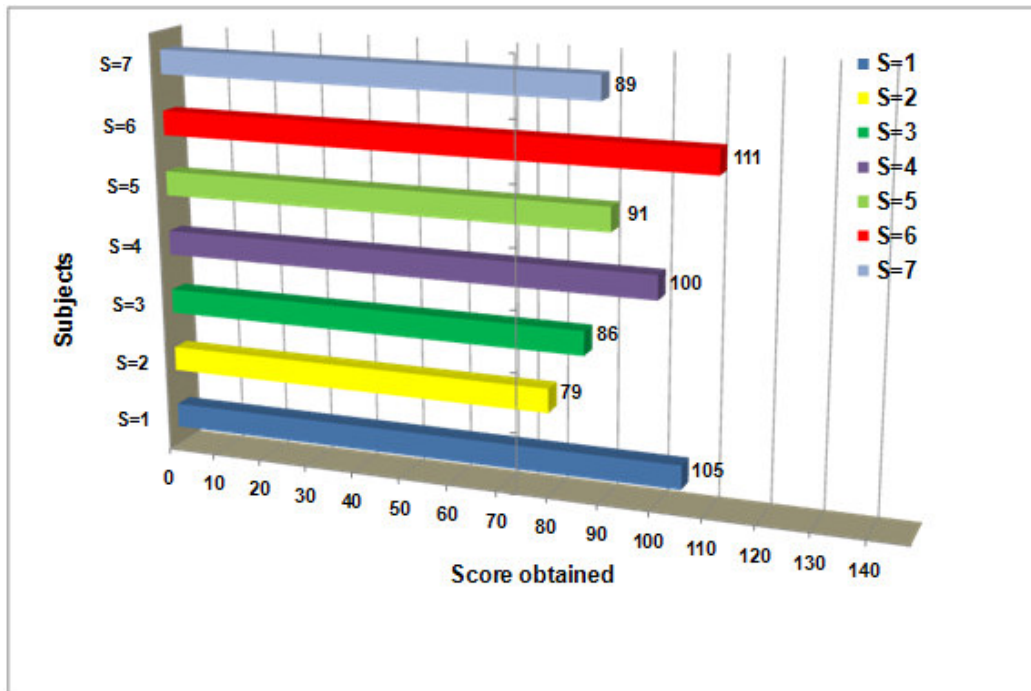
#### **4.3. SUB-AIM 2: The self-reported subjective outcomes of subjects with BCIs**

This study proposed as a second sub-aim to determine the self-reported subjective outcomes of the subjects with BCIs. In the current study, receiving a second CI was found to provide two subjects with auditory thresholds indicative of normal hearing and the remaining subjects (N=5) with auditory thresholds indicative of a mild hearing loss. The change in degree of hearing loss as determined with audiometric testing led the researcher to question the extent of the advantage perceived by the subjects in everyday listening conditions. This part of the investigation was based on the surmise that audiometric testing alone does not provide sufficient information about person's hearing ability in every-day listening situations and that certain variables may have an effect on a person's perception of his / her hearing ability.

The variables may include the BCI recipient's performance with his / her unilateral cochlear implant, the reason for obtaining the second CI, expectations of his / her performance with a second CI, preferred method of communication, type of social and cultural activities in which the BCI user participates, and the BCI user's support network that may include the professional team involved, family members, and friends. In the light of the wide spectrum of factors that may have an effect on a person's perspective of him / her self, it became apparent that there was a need to investigate not only the subjects' subjective outcomes with regard to their hearing ability since receiving the second CI, but also other factors that might impact on the BCI recipient's QOL. In this study communicative, contextual, and psychosocial factors were explored. The section that dealt with communication activities, explored the subjects' speech and hearing performance, including spatial orientation, quality of sounds, and speech perception in quiet and in noise. The second section investigated contextual factors including environmental factors such as work related issues, financial implications and safety measures. The third and

last section explored the subjects’ subjectively perceived social participation in activities involving friends, family and colleagues.

All the subjects with BCIs completed the *Questionnaire for the subject with BCIs* and all achieved a result above the base line value of 74, indicative of positive subjective outcomes with BCIs. A line diagram illustrating each subject’s score relative to the baseline value of 74 is presented in Figure 4.2.

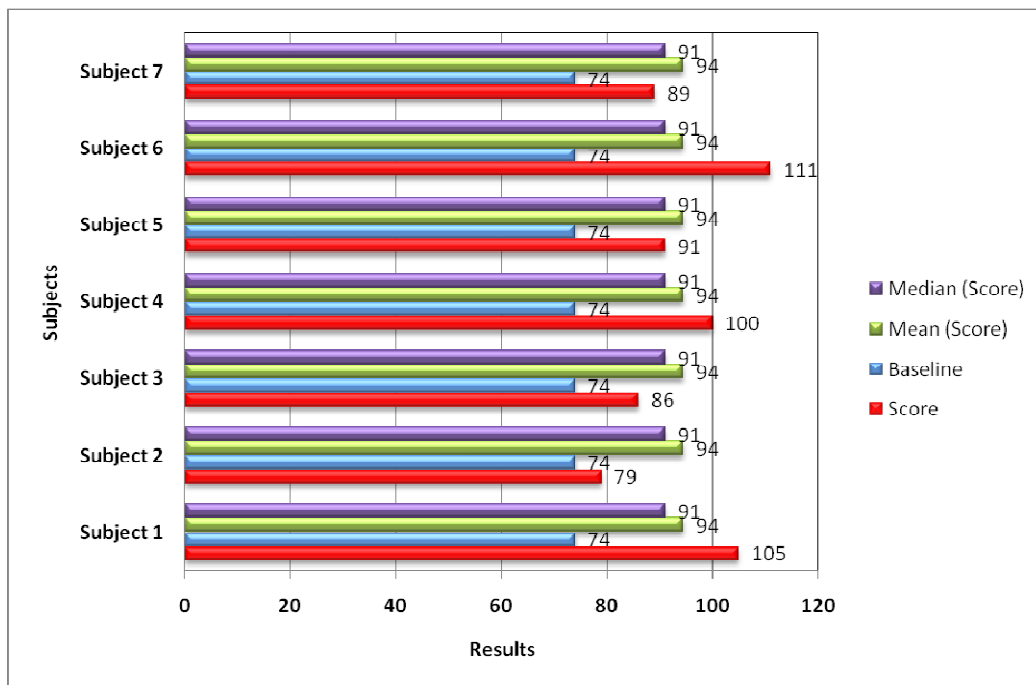


**Figure 4.2: Subjects with BCIs’ scores in the Questionnaire for the subject with BCIs**

Figure 4.2 illustrates clearly that all the subjects with BCIs obtained results above the baseline value of 74 (i.e. a percentage of 50% or higher), indicative of positive subjective outcomes with BCIs. As presented in Figure 4.2 it is clear that three subjects obtained significantly higher results than others which are indicative of remarkably positive subjective outcomes. These subjects achieved scores above the mean result.

The mean of a numeric variable is calculated by adding the values of all observations in a data set (the subjects’ scores in the questionnaire) and then dividing that sum by the number of observations in the set (seven subjects). This

provides the average value of all the data (Statistics Canada, 2008, accessed March 24, 2009). The mean test score, as statistically determined using the test scores of all the subjects with BCIs, was 94. The median value, a value that corresponds to the middle observation if the observations of a variable are ordered by value, was statistically determined at 91. The fact that the mean and the median test scores were closely rated, suggested a well balanced sample profile, as illustrated in Figure 4.3.



**Figure 4.3: Subjects with BCIs test scores relative to the baseline value, mean, and median**

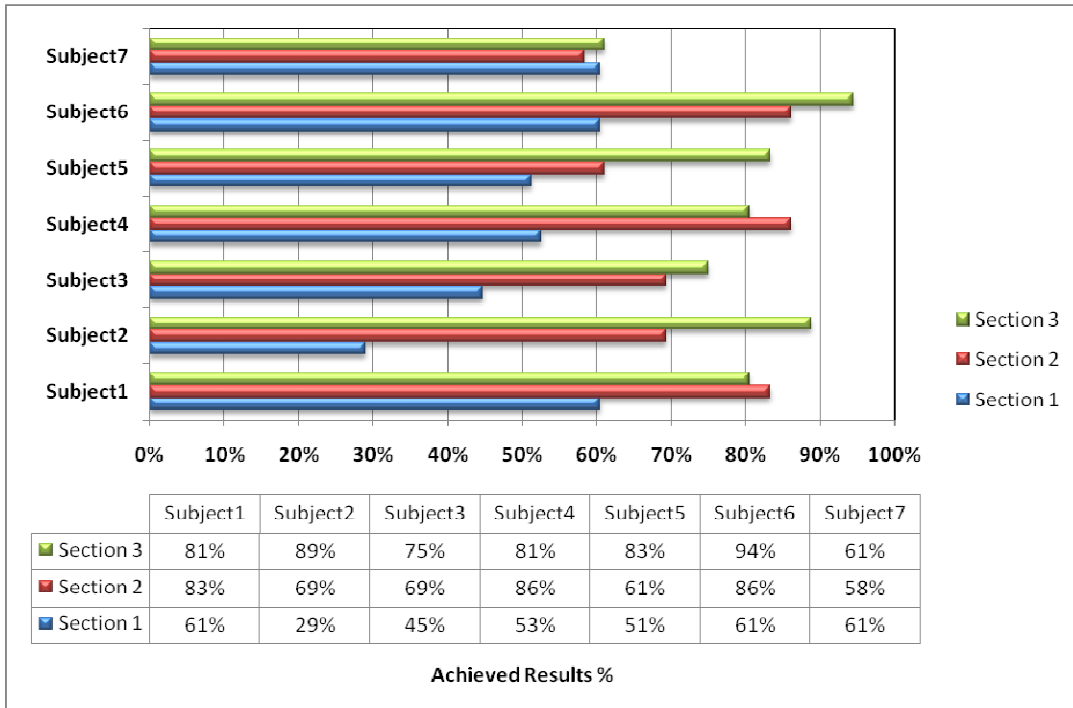
Figure 4.3 illustrates clearly that the subjects achieved test scores above the baseline value of 74 (i.e. a percentage of 50% or higher). When compared to the mean, the findings suggest that all the subjects obtained positive subjective outcomes from BCIs that were more significant for subjects 1, 4 and 6. This finding supports the phenomenon that was explored in this study: individuality appears to be the key factor determining the outcomes of BCIs. Table 4.6 provides further data about the subjects' individual test scores in the different sections explored in the *Questionnaire for the subjects with BCIs*, their total test scores, the baseline value, the results being the subjects with BCIs' test scores expressed as a percentage, the mean, and the median scores also expressed as a percentage.

**Table 4.6: Scores obtained in the questionnaire for the subjects with BCIs**

Subjects	Section 1	Section 2	Section 3	Score Totals	Baseline	Results	Mean Score	Median Score
S=1	46	30	29	105	74(50%)	71%	94(64%)	91(61%)
S=2	22	25	32	79	74(50%)	53%	94(64%)	91(61%)
S=3	34	25	27	86	74(50%)	58%	94(64%)	91(61%)
S=4	40	31	29	100	74(50%)	68%	94(64%)	91(61%)
S=5	39	22	30	91	74(50%)	61%	94(64%)	91(61%)
S=6	46	31	34	111	74(50%)	75%	94(64%)	91(61%)
S=7	46	21	22	89	74(50%)	60%	94(64%)	91(61%)

Table 4.6 provides a comparative illustration that depicts the subjects' results expressed as a percentage and it is clear that all the subjects achieved scores above 50%. Furthermore, Table 4.6 contains information about each of the subjects with BCIs' scores that were obtained in each of the sections that were explored, and their total scores obtained relative to the baseline, mean-, and median scores. The researcher realized that more in-depth analysis of the subjects' results obtained in each section, the qualitative analysis of the responses obtained in the semi-structured interview, and the answers to the open-ended questions in the *Questionnaire for the subject with BCIs* (questions 14, 16, 19, 20, 21, 25, 33, 36, 40, 42, 47 and 49) may assist in explaining the subjective results that proved to be more significant for some (N=3).

Analysis of the subjects' performance (scores obtained and expressed as a percentage) in each of the different sections that were explored are presented in Figure 4.4.



**Figure 4.4 Comparison of the results obtained in each section in the questionnaire for the subjects with BCIs**

It is interesting to note that all the subjects performed better in section 2 and 3 than in section 1. Section 1 investigated benefits related to communication; section 2 investigated benefits related to contextual factors; and section 3 explored benefits in psychosocial issues.

This finding was in disagreement with previous research that found subjective benefits with BCIs to be particularly concerned with benefits in hearing and improved communication (MED-EL, 2003, accessed May 22, 2007). In the current study, the majority of the subjects' subjective reports indicated an improved perception of sound being more natural and clear; improved speech understanding regardless of the position of the speaker; and an improved ability to discriminate speech in the presence of competing noise and in addition remarkable improvement in contextual and psychosocial factors.

The responses to the open-ended questions in the *Questionnaire for the subject with BCIs* and in the semi-structured interview were qualitatively analysed. The specific aspects that were explored involved the BCI-users' ability to have a conversation on the telephone and to listen to music; the extent to which the BCI-

users relied on visual cues, e.g. speechreading as a compensatory strategy to understand a spoken message; the BCI-users' perceptions of the benefits and perhaps the continued restraints in psychosocial matters as a result of their current hearing abilities; the BCI-users' perception of their ability to perform listening tasks that require binaural hearing; and the BCI-users' remarks on the cost-effectiveness of a second cochlear implant.

The specific aspects that were explored in the open-ended questions involved tasks that people, who live in the contemporary world, are expected to carry out, as well as psychosocial matters that may add to a person's quality of life. All the subjects were asked to give a personally formulated definition of the term 'quality of life'. The individual responses to the open-ended questions in the *Questionnaire for the subject with BCIs* and in the semi-structured interview are provided in Table 4.7.

**Table 4.7: Subjective reports by subjects with BCIs**

SUBJECT	SUBJECTIVE OUTCOME
S=1	Subject one was <i>always</i> able to follow a telephone conversation and preferred using her left ear. S=1 reported that although music was not yet optimally perceived as 'clear and natural', she enjoyed listening to it. S=1 indicated that she was able to speechread and rated her speechreading competency with one CI as 'average' but with two CIs as 'good'. According to S=1 the softest sounds in her environment that she was unable to hear included footsteps in the house and people talking outside. S=1 indicated that it was her significant other person's (SOP=1) decision to apply for a second CI, as she was underage (i.e. younger than 18 years) at the time the opportunity arose. According to S=1, receiving a second CI has led to positive changes in the quality of her relationship with friends, an improved self-esteem and feeling of self-confidence as well as changes in hearing ability especially improved speech discrimination in noise. Despite many positive changes, S=1 still preferred watching DVD's at home where subtitles are readily available rather than going to the public cinema. In general S=1 indicated that BCIs helped her to hear sounds more clearly and from a further distance. S=1 gave the

**Table 4.7: Subjective reports by subjects with BCIs (continued)**

SUBJECT	SUBJECTIVE OUTCOMES
S=1	<p>example of being able to listen to the class-teacher by means of her frequency modulated (FM) system while hearing her friends talk with the other ear. S=1 and her significant other person were both of the opinion that obtaining a second CI was worth every expense and that BCIs contribute towards her QOL. For the subject and her significant other person, 'QOL' meant to be able to listen to music, attend a normal mainstream school and have friends that treated her as an equal. The reason for obtaining a second CI was to improve her ability to discriminate speech in noise, develop localization acuity and also experience improved technology with the second CI, which has 24 electrodes as opposed to the first CI's 22 electrodes.</p>
S=2	<p>S=2 indicated that she was <i>seldom</i> able to follow a conversation over the telephone. She depended on both CIs and a 'speaker phone' option at the times when she did succeed in following a telephone conversation. S=2 specified that she did not enjoy listening to music and perceived music as a monotonous rumble as she was unable to differentiate between the instruments playing. Despite her dislike of music, she had noticed a difference in her ability to differentiate between the melodies and the lyrics of song since receiving the second CI. S=2 commented that she had hoped to be able to enjoy music to a greater extent after receiving the second CI, especially because her significant other person devoted a great part of his life to music. According to S=2 she became accustomed to speechreading as a compensatory strategy for her hearing loss without realizing how dependent she was on visual information to understand speech, until the age of 35, when her SNHL was first diagnosed. The diagnosis followed shortly after her colleagues at work noticed that she was unresponsive to speech especially when the speaker was behind her. Although in the questionnaire S=2 did not indicate any change in competency in speechreading since receiving her second CI, she mentioned in the interview that her dependence on speechreading had reduced since receiving the second CI, due to her improved hearing</p>

**Table 4.7: Subjective reports (continued)**

SUBJECT	SUBJECTIVE OUTCOME
S=2	<p>acuity. S=2 was unaware of the softest sounds in her environment that she did not hear. S=2 decided to apply for a second CI after her audiologist instigated the treatment option for her bilateral SNHL. No change in the quality of her relationships with her friends or family was indicated. S=2 reported that she benefited from BCIs in her improved ability to understand speech in noisy listening conditions. As a result of her improved communication skills she was more outgoing and no longer had to rely on speechreading as much as before. She added that since receiving the second CI she was able to follow a discussion between two people even when she was not a part of or in close proximity to the conversation. Finally S=2 explained that she heard 50% less with one CI than with BCIs. She further explained that although she perceived her hearing with BCIs to be enhanced, it was only after 18 months of regular mapping that she felt comfortable with the sound. While some researchers have observed benefits from BCIs only two months post-bilateral implant activation (Müller, Schon &amp; Helms, 2002) others recommend that a longer period of time be allowed for adaptation to optimize bilateral use and functioning before any testing commences (Litovsky et al., 2004). From S=2's experience it is obvious that the human brain takes time to learn to process the two signals perceived from two ears and to create one import. This process takes longer for some BCI users than for others. Despite S=2's current most favourable map and definite objective and subjective improvements in hearing, she was reluctant to say that BCIs had changed her psychosocial wellbeing or QOL. Although S=2 and her significant other person, SOP=2, obtained scores indicative of positive subjective benefits, she was of the opinion that apart from the people that she had met since her first cochlear implantation, BCIs were not related to any direct changes in her QOL. Additionally she emphasized that since receiving the second CI she had met other people with BCIs and was at that time an active member of an online supporting network. For S=2, QOL had to do with being able to communicate with others (which she</p>



**Table 4.7: Subjective reports (continued)**

SUBJECT	SUBJECTIVE OUTCOME
S=2	does mainly via the internet) and being able to feel safe.
S=3	<p>S=3 indicated that he was <i>often</i> able to follow a telephone conversation and preferred using his right-ear when doing so. In addition, he indicated that he was unable to follow what two people were saying at once, for example while having a telephone conversation he is unable to follow a person who speaks next to him. Furthermore, S=3 indicated that he did not enjoy listening to music and was only <i>sometimes</i> able to identify the instruments playing. The sound is not perceived as clear and natural. S=3 indicated that he was able to speechread and rated his speechreading ability as 'good' with no reported change since receiving the second CI. The softest sound that he reportedly was unable to hear was a person whispering. S=3 reported an increase in his annual income after receiving the second CI as opposed to just before the second implant. Although some other variables may be involved, this is a remarkable outcome. This increase in his annual income was confirmed by his significant other person (SOP=3) in the <i>Questionnaire for the significant other person</i>. S=3 revealed that many people were involved in the decision to apply for a second CI including an Ear Nose and Throat (ENT) specialist, an audiologist and his significant other person. S=3 indicated an improvement in the quality of his relationship with his co-workers and friends after receiving his second CI. In addition, S=3 indicated that BCIs had brought positive changes in his hearing ability, an improved self-esteem and feeling of self-confidence, better speech discrimination in noise, and a reduced feeling of anxiety and frustration. Even though he subjectively perceived the positive changes mentioned above, he indicated that he still avoided watching movies without subtitles and going to musicals or other theatrical productions. S=3 also stated, however, that BCIs had altered his life in such a way that he was more social since receiving the second CI due to improved communication skills. For S=3, the term QOL meant being able to participate actively and independently in any activity you undertake, whether it be a conversation between</p>



**Table 4.7: Subjective reports (continued)**

SUBJECT	SUBJECTIVE OUTCOMES
S=4	more actively in conversations and perceived an increased sensitivity in hearing.
S=5	<p>S=5 indicated that she was <i>usually</i> able to follow a conversation on the telephone and that she preferred using her left ear. She was unable to follow what two people were saying simultaneously as in the scenario where a person next to her started talking while she was having a telephone conversation. S=5 indicated that she enjoyed listening to music and that the sound was <i>regularly</i> perceived as clear and natural. She indicated that she was only sometimes able to differentiate between the different instruments that were playing. Furthermore S=5 was able to speechread and rated her competency as <i>good</i> with one and with two CIs. She indicated that the softest sounds in her environment that she was unable to hear were people whispering. S=5 indicated no change in her income after receiving a second CI and no change in the quality of her relationships with friends or colleagues after receiving the second CI. S=5 indicated that it was her own decision to apply for a second CI and that positive changes in hearing ability and speech discrimination in noise were subjectively noticed. S=5 specified that she still avoided going to music concerts and participating in water activities. This was also revealed in the semi-structured interview when S=5 mentioned that although she used to be fond of swimming she avoided participating in water activities since receiving her first CI due to not being able to communicate with others during the activity and also afterwards having to wait for her hair to dry before putting back the CI devices. One benefit that she was very grateful for after receiving her second CI was her renewed ability to identify and appreciate the melody of music. She declared, in a humorous aside, that shortly after the second CI was switched on, she started noticing an increase in her monthly mobile phone account. She explained that the increase in the phone account is evidence of the more frequent use of her mobile phone. During the semi-structured interview she acknowledged definite changes in hearing. She</p>

**Table 4.7: Subjective reports (continued)**

SUBJECT	SUBJECTIVE OUTCOMES
S=5	<p>specified that after receiving the second CI she was able to hear low frequency sounds as opposed to hearing only higher frequency sounds with one CI. S=5 also revealed in the interview that she seemed to be better able to monitor the volume of her own voice after receiving the second CI. She perceived her own voice to be much softer in intensity than before. Although she indicated that she was able to recognize definite changes in her hearing sensitivity, this did not contribute towards any changes in her QOL. According to S=5, QOL is about achieving your personal goals and doing the best you can in everything you attempt. With this personal definition of QOL, as frame of reference, S=5 did not give BCIs credit for contributing to the success she had achieved in life.</p>
S=6	<p>S=6 indicated that she was usually able to follow a conversation on the telephone and that she preferred using a phone-assistive device based on blue tooth technology. She reported that she was <i>sometimes</i> able to follow what two people were saying simultaneously given the example of following a telephone conversation when someone next to her starts talking. S=6 enjoyed listening to music and was regularly able to identify the music instruments playing. She sometimes perceived the sound of music to be clear and natural. S=6 indicated that although she was able to speechread she perceived a decrease in her ability to speechread since receiving the second CI. This could be indicative of subjective gain from the audiometric benefits associated with BCIs as she no longer had to rely on visual information to the same extent as before receiving the second CI. S=6 indicated that it was her own decision to apply for a second CI. She did not indicate any sounds that she was unable to hear in her environment and no change in her annual income was revealed. Positive changes in hearing ability, improved self-esteem and confidence, better speech discrimination in noise and less anxiety and frustration were disclosed. S=6 indicated that she avoided attending parties where loud music was likely to be played and stated conclusively that she was much happier since receiving her second CI. Furthermore she had noticed that</p>

**Table 4.7: Subjective reports (continued)**

SUBJECT	SUBJECTIVE OUTCOMES
S=6	<p>her work required less concentration than before. Concentration and listening are intrinsically linked to learning and understanding. This subject needed to pay attention and listen in meetings. Hearing loss often jeopardizes these skills as more effort is needed to maintain concentration and listening. This in turn can cause fatigue and at times, frustration (Hicks, Tharpe &amp; Wilkerson 2002:573). During the interview, both S=6 and SOP=6 reported positive subjective outcomes including improved localization acuity, improved ability to hear soft sounds, and an improved ability to monitor the volume of her own voice. S=6 indicated that since receiving the second CI she perceived her own voice's fundamental frequency at a lower intensity than before. For S=6 the term QOL meant to have good interpersonal relationships with others and to be self-supporting. Other noteworthy comments made in the interview included reference to the importance of support and counseling by the cochlear implant team. In addition, the subject reported a definite feeling of enhanced independency in daily conversations and especially at work.</p>
S=7	<p>S=7 indicated that she was <i>sometimes</i> able to follow a telephone conversation and preferred using her right ear. She was only sometimes able to follow what two people were saying simultaneously. S=7 indicated that she enjoyed listening to music as she <i>always</i> perceived the sound to be clear and natural. Furthermore, she indicated that she was always able to identify the different instruments when a song was playing. S=7 was also able to speechread and rated her ability to do so with one CI as <i>good</i> and with BCIs as <i>excellent</i>. S=7 indicated that the softest sound that she was unable to hear was the rustle of leaves. S=7 stated that it was her own decision to apply for a second CI and although it did not affect the quality of her relationships with friends it did improve her self-esteem and self-confidence. For S=7 the term QOL meant to be able to build relationships with others and to help others less fortunate. S=7 indicated that despite these perceived benefits she was still reluctant to go to places where people unfamiliar to her might ask about her hearing loss. In</p>

**Table 4.7: Subjective reports (continued)**

SUBJECT	SUBJECTIVE OUTCOMES
S=7	conclusion, however, she stated that BCIs had altered her life in such a way that she was more self-confident in everything that she did.

A summary of the responses obtained in the open-ended questions in the *Questionnaire for the subject with BCIs* and in the semi-structured interview are presented and discussed with reference to with the specific functions that were explored. Few comments were made on the surgical and anaesthetic procedures, the additional costs, mappings and counselling sessions required, and the cosmetic appearance of having two devices.

#### 4.3.1 Ability to follow a telephone conversation

Four subjects with BCIs indicated that they were able to follow a telephone conversation using the hand piece held against a specific ear (not related to the ear that was implanted first). Two of the remaining three subjects indicated that they were able to follow a telephone conversation with the help of a phone assistive device. S=2 indicated that she was able to follow a telephone conversation when the speaker phone setting was used and with both CIs switched on. This subject also indicated that her preferred method of communication was via the internet. This subject explained that she preferred not only using the internet because it does not require fine hearing acuity, but simply because her greatest support system was online. Another subject (S=6) indicated that she was able to follow a telephone conversation with an assistive device based on blue tooth technology. Only one subject (S=4) indicated that he was unable to follow a telephone conversation and preferred using text messaging or electronic mailing to correspond with others over long distances. It is clear that the majority of the subjects (N=6) can understand a great deal of speech through listening alone as they indicated that they were able to have a conversation on the telephone.

#### 4.3.2 Ability to listen to music

Five of the seven subjects with BCIs indicated that they enjoyed listening to music and one subject (S=5) resumed playing the piano after receiving the second CI. This subject also indicated that since receiving the second CI, she was able to listen to and appreciate new music, i.e. music that she had not heard prior to the onset of her hearing loss. One of the two subjects who indicated that they disliked listening to music admitted to a change in her ability to distinguish between the melody and the lyrics in songs since receiving the second CI. Her inability to enjoy music was one aspect that she had hoped to change with BCIs as her significant other person devoted a significant part of his life to music. The other subject (S=3) who indicated that he did not enjoy listening to music reported that he was only *sometimes* able to identify the instruments playing and the sound was not perceived as clear and natural.

Mirza, Douglas, Lindsey, Hildreth and Hawthorne (2003:85) conducted a study to assess the appreciation of music after cochlear implantation in adult patients. This topic was suggested by the fact that many cochlear implant candidates expressed hopes of enjoying music following implantation. Their results showed that listening to music after implantation was more likely in younger patients, those with higher speech perception scores, and those with a shorter term of deafness. Listening to music was not found to be related to gender, type of implant, processing strategy, time since implant, or music enjoyment before becoming deaf. They concluded that appreciation of music after cochlear implantation was disappointingly low and recommended that future developments in implant technology strive to improve satisfaction with regard to listening to music. The finding that the majority of subjects in this study (N=5) enjoyed listening to music since receiving the second CI suggests that BCIs can offer unilateral cochlear implant users with the potential to enjoy music.

#### 4.3.3 Ability to speechread

All seven subjects indicated that they were able to speechread. The majority of subjects (N=4) perceived *no change* in their ability to do so with two CIs compared to one CI. One of the subjects, S=2, who indicated *no change* in her ability to

speechread in the questionnaire, reported in the interview that her speechreading ability had reduced since she received her second CI, due to her improved hearing acuity. S=2 explained that she unwittingly became accustomed to speechreading as a compensatory strategy for her hearing loss. As her increasing ability to speechread helped her to continue to understand the speech of others when the visual information was available, she did not realize the extent of her hearing loss. Her SNHL was only diagnosed after her colleagues at work made her aware of her unresponsiveness to speech, especially when the speaker was behind her. Only one subject, S=6 indicated on the questionnaire that she experienced a decrease in her ability to speechread since receiving the second CI. Two subjects, S=1 and S=7, indicated that they perceived an increase in their ability to speechread with two CIs as opposed to one CI. Although speechreading ability may be complimented by the subject's improved hearing acuity with BCIs, a BCI user's skill may gradually decrease as the need for speechreading as compensatory strategy for the hearing loss is reduced with improved hearing acuity. The sound quality delivered by two cochlear implants may be adequate, so that the user does not have to rely on speechreading to the same extent.

#### 4.3.4 Challenging listening situations

Several different situations that involve potentially challenging acoustic environments were revealed. Two subjects indicated that they preferred watching DVD's at home where subtitles are readily available rather than going to the public cinema. Two other subjects stated that they still avoided going to noisy settings such as shopping malls and motorcar or motorcycle racing events, where many people are present and background noise can be overwhelming. Three subjects revealed that they avoided attending musicals, theatrical productions, and social activities where loud music was likely to be played and they might be expected to participate in a conversation at the same time. In addition, one of the three subjects mentioned somewhat disconsolately that she avoided participating in water activities such as swimming with friends. She explained that although she used to enjoy such activities, she no longer took part due to her inability to participate in the conversation during swimming and even shortly afterward, as she had to wait for her hair to dry before putting her CI devices back on. One subject indicated that



she avoided attending situations where people who were unfamiliar to her might ask about her hearing loss and / or devices.

The benefits of the perceived auditory outcomes in daily listening situations were particular to each individual and the subjects' unique experiences seemed to be related to their interests, preferred method of communication, and previous participation in activities. Although the majority of the subjects obtained significant auditory outcomes in the audiometric testing, they still avoided certain situations, which was indicative of the continued impact of the hearing loss on participation in activities, a subjective measurement of QOL. According to Peters (2006:2) many individuals with hearing loss withdraw from social and occupational functions that present challenging or complex acoustic environments.

#### 4.3.5 Psychosocial benefits

Despite the challenging listening situations that some subjects still avoided after receiving the second CI, the majority of the subjects (N=5) in this study reported that BCIs added to QOL. Each subject was asked to provide a personalized definition of the term QOL. The majority of the subjects included in their definitions that QOL involved being able to communicate with others, to participate in any activity (social, cultural and physical) you wish to pursue, to be self-supporting and independent, to build interpersonal relationships, and to be treated equally. The five subjects who indicated that BCIs contributed to their QOL concurred that since receiving the second CI, they experienced the factors included in their definitions of QOL. Although the remaining two subjects obtained high scores in the section that investigated psychosocial benefits after receiving the second CI, they were reluctant to say that BCIs directly contributed to changes in their QOL.

In conclusion, the majority of the subjects reported subjective benefits from BCIs that were not only related to benefits in hearing, for example an enhanced understanding of speech in the presence of noise, but were also related to changes in the subjects' quality of life. This was revealed in the subjects' reports that the auditory benefits provided the BCI user with improved communication skills that contributed to an enhanced feeling of self-confidence and self-esteem. This in turn provided the BCI user with internal advocacy to be more participative in activities.

This finding compared to the definition provided by the WHOQOL (1995, in Phillips, 2006:33) that describes QOL as “the subjective evaluation of an individual’s perspective of their position in life which is embedded in cultural, social and environmental contexts”. This positive subjective outcome was in most cases not only perceived by the subject but also acknowledged by the significant other person.

#### 4.3.6 Benefits related to binaural hearing

As explained in previous chapters in this study, the three primary effects of binaural hearing are: the head shadow effect, the binaural summation effect, and the binaural squelch effect. According to Brown and Balkany (2007:316), the capacity of BCI users to utilize these effects ultimately determine the degree of additional benefit that a second implant will provide. Research to date has demonstrated variable benefits of each effect for bilateral implant users. The subjects in this study also revealed distinct findings (objective and / or subjective) related to binaural hearing.

All the subjects were able to perform the speech in noise tests. Three subjects were able to discriminate speech when presented in the presence of interfering background noise at a SNR of +10dB and four subjects were able to discriminate speech in noise at +15dB SNR. In addition, the majority of the subjects indicated that they subjectively perceived an enhanced ability to follow a conversation and to discriminate speech in the presence of competing noise. The improvement in the subjects’ ability to discriminate speech in noise and the consistent subjective perception of an enhanced ability to spatially separate speech and noise during everyday listening conditions since receiving the second CI, may be related to the head shadow effect (Firszt, Reeder & Skinner, 2008:750).

Furthermore, S=1 indicated that she was able to follow what was being said by two persons simultaneously, in two different scenarios. The first situation involved her ability to follow a telephone conversation when someone next to her starts talking, and the second her ability to listen to the teacher by means of her FM-system with one ear while being able to hear what her friends in class were saying to one another. This could also be indicative of an improvement in the ability to benefit

from the binaural squelch effect with a second CI. The binaural squelch effect allows the brain to separate meaningful signals from noise coming from different directions, by comparing time, intensity, and pitch differences between the two ears. It is important to note that this specific BCI user was not congenitally deaf, but became deaf at a young age. Fortunately she received her first CI at a young age. Her history of hearing loss and early implantation may contribute to her advanced ability to follow two different conversations taking place at the same time.

Another subjective perception of binaural hearing was revealed in the statement made by S=2. According to this subject, she hears 50% less with one CI than with BCIs. This could be indicative of the binaural summation / redundancy effect that enables a person to perceive a sound that is heard binaurally as *twice as loud* as one heard monaurally, and the hearing sensitivity of the person to be aware of small increases in intensity and frequency. A different subject indicated that she found the tasks that previously required intense attention and concentration less tiring than before receiving the second CI. Poor hearing jeopardizes a person's ability to concentrate, and conscious effort is required to maintain attention; which, in turn, causes fatigue (Hicks, Tharpe & Wilkerson 2002:573). This subjective outcome is indicative of a perceived benefit in their hearing acuity that can be related to the binaural summation / redundancy effect.

#### 4.3.7 Cost effectiveness

Although the issue of cost-effectiveness was discussed in previous chapters, this study did not include a cost utility ratio or propose to determine the cost effectiveness of BCIs as intervention strategy. Nevertheless, a few subjects felt compelled to elaborate on this issue and in some cases provided possible solutions as to how manufacturers can help reduce the cost of obtaining a second CI device. During the semi-structured interview, S=2 and SOP=2 expressed the opinion that CIs are generally overpriced. The subjects argued that due to the perceived outcomes of CIs, every suitable candidate should be able to receive a CI as intervention for her / his hearing loss. In South Africa, the government does not provide funding or contribute towards a cochlear implant. Consequently, the costs involved in obtaining a CI are unrealistic for some, especially those without medical aid funding. S=2 suggested that manufactures lower the cost of the first CI to grant

all candidates the opportunity to enjoy some hearing sensation and lower the cost of the second CI by avoiding money spent on unnecessary and excessive items already included in the first CI package (i.e. batteries, cleaning material etc.). S=2 strongly recommended a CI for *everyone* and a second CI for *anyone* who can meet the expenses. The majority of subjects with BCIs agreed that although BCIs as intervention type are expensive, no 'price' can be affixed to superior hearing. All the subjects reported that they felt 'privileged' to have two CIs and recommended at least one CI to any candidate in search of improved hearing. They explained that it would allow the recipient to experience the marvel of improved hearing sensation to a certain degree. The subjects also agreed that a unilateral cochlear implant user who meets the criteria to obtain a second CI has the advantage of receiving a technologically more advanced CI at a later time.

#### 4.3.8 Review of sub aim 2

From these results, it is clear that the subjects with BCIs who participated in this study gained positive subjective outcomes in everyday listening conditions. Some of the findings were in agreement with previous research findings. Summerfield et al. (2002) found significant improvements in subjective spatial hearing, quality of hearing, and hearing for speech. In a questionnaire format, Senn, Kompis and Vischer (2005, in Brown & Balkany, 2007:317) determined positive subjective benefits with BCIs with regard to sound localization and speech discrimination in quiet and noisy conditions. Another supporting study used the validated 'Abbreviated Profile of Hearing Aid Benefit' questionnaire on 30 simultaneously bilaterally implanted subjects and found significant benefits to subjects in communication, listening under reverberant conditions, and listening in a noisy environment (Litovsky, Parkinson & Arcaroli 2006:714). Although the subjects in the current study all received sequential bilateral cochlear implants, according to Peters (2006:7) the long-term subjective outcomes for sequentially and simultaneously bilaterally implanted subjects have been found to correlate.

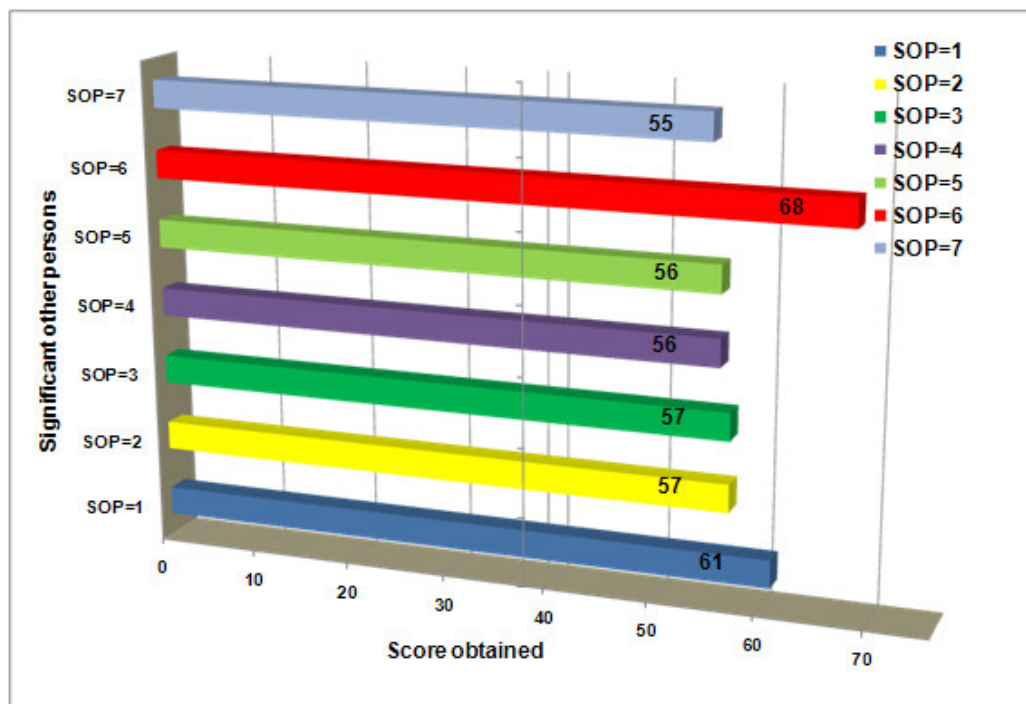
It is clear that previous studies found subjective benefits that were particularly related to benefits in hearing and communication. In the current study, the subjects reported benefits in not only communication activities but also in factors related to contextual and psychosocial factors associated with a person's QOL. Overall, all

the subjects with BCIs obtained scores above the baseline value that was set as criterion and indicative of positive subjective outcomes with BCIs. Firszt, Reeder and Skinner (2008:750) also found the clinical scores obtained in their study to be supported by their subjects with BCIs' subjective experiences.

#### **4.4 SUB-AIM 3: The subjective outcomes of BCIs as perceived by a significant other person of the subjects with a BCI**

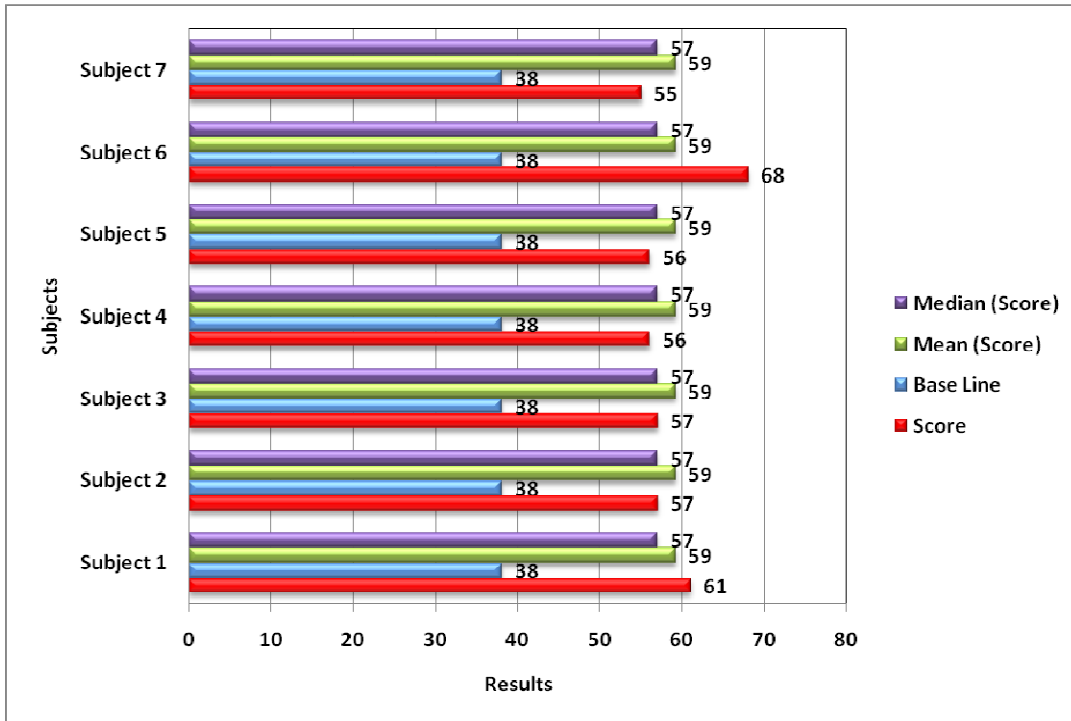
The third sub-aim was to determine the subjective outcomes of the subject with BCIs from a significant other person's perspective. The researcher realized that the inclusion of a significant other person may assist in determining a more holistic view of the subjective outcomes of BCIs in everyday listening conditions and in domains related to QOL. The prediction was made that the inclusion of a significant other person in this study would not only verify the subjective outcomes of each subject with BCIs, but also provide additional data related to the person's performance in everyday listening situations since receiving the second CI as well as other aspects related to the BCI-users' general well-being and QOL that may have changed.

Knutson, Johnson and Murray (2006:280) found that people with disabilities sometimes seek services because of the influence of their "significant other", often the spouse. Knutson et al. (2006:280) state that some significant other persons are so involved that they influence a subject's judgment in decision making. These findings were incorporated in this study, by not only including the significant other as a subject but providing the significant other with a questionnaire that contained similar questions to the questionnaire for the subject with BCIs and by encouraging the significant other to participate in the interview. The scores obtained by the significant other persons in the *Questionnaire for the significant other* are illustrated in Figure 4.5, below.



**Figure 4.5: Significant other persons' scores in the *Questionnaire for the significant other person* of the subject with BCIs**

Figure 4.5 clearly illustrates that all the significant other persons completed the *Questionnaire for the significant other person* and obtained scores above the baseline value of 38 (i.e. a percentage of 50% or higher). Any score above the baseline value was considered indicative of positive subjective outcomes with BCIs as perceived by the significant other person. Two significant other persons obtained exceedingly high scores far above the mean, a score of 59. The results are illustrated in Figure 4.6 below.



**Figure 4.6: Significant other persons' test scores relative to the baseline value, mean and median**

As can be seen in Figure 4.6, the mean of 59 was due to the slightly higher and outlier score achieved by SOP=6. When compared to the median score of 57 (the median being a value that corresponds to the middle observation if the observations of a variable are ordered by value), the number of significant other persons who achieved higher scores, increased. As can be seen in Table 4.7, four significant other persons achieved scores above the median.

Table 4.8 provides a detailed analysis of the significant other persons scores' in the different sections of their questionnaire, their total test scores, the baseline value, the test scores expressed as a percentage, the mean, and the median scores.

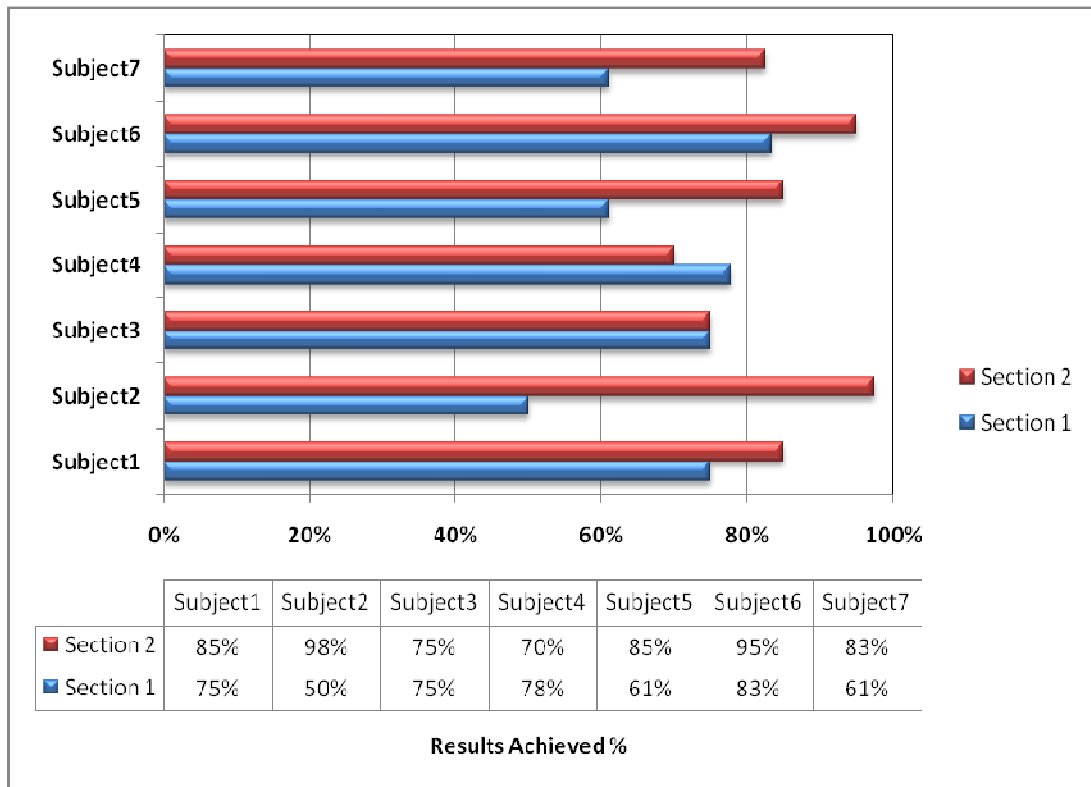
**Table 4.8: Scores obtained in the questionnaire for the significant other**

Subjects	Section 1	Section 2	Scores	Base Line	Results	Mean Score	Median Score
S=1	27	34	61	38 (50%)	80%	59 (77%)	57 (75%)
S=2	18	39	57	38 (50%)	75%	59 (77%)	57 (75%)
S=3	27	30	57	38 (50%)	75%	59 (77%)	57 (75%)
S=4	28	28	56	38 (50%)	74%	59 (77%)	57 (75%)
S=5	22	34	56	38 (50%)	74%	59 (77%)	57 (75%)
S=6	30	38	68	38 (50%)	89%	59 (77%)	57 (75%)
S=7	22	33	55	38 (50%)	72%	59(77%)	57 (75%)

Table 4.8 provides a comparative illustration and presentation of the significant other persons' scores in relation to the baseline, mean and median values. When expressed as a percentage, the significant other's results clearly indicate that all the significant others achieved scores above 50%, and two significant other persons' results exceeded the mean result of 77%. When brought in relation to the median result, a value less sensitive to extreme scores that can cause highly skewed distributions, as in the case of SOP=6, the median makes a better measure than the mean. When compared to the median, the majority of the significant others scores (N=4) exceeded the median value.

As previous research showed benefits that were particularly related to benefits in hearing and communication (Senn, Kompis and Vischer, 2005, in Brown & Balkany, 2007:317; Summerfield, 2002), the current researcher thought that changes in contextual and psychosocial matters might be more subtle and perhaps not as significant to the subject with BCIs as to his / her significant other person. The sections in the *Questionnaire for the significant other person* explored the contextual (section 1) and psychosocial (section 2) factors, relating to the subject with BCI's QOL from a significant other person's perspective.





**Figure 4.7: Comparison of the results obtained in each section in the questionnaire for the significant other person**

In Figure 4.7, the results obtained by the significant others clearly illustrate that the majority of the significant others was of the opinion that the subjects with BCIs especially benefited from BCIs in psychosocial factors related to QOL. The researcher realized that more in-depth analysis of the responses obtained in the semi-structured interview and the answers to the open-ended questions in the *Questionnaire for the subject with BCIs* (questions 14, 16, 19, 20, 21, 25, 33, 36, 40, 42, 47 and 49) may assist in explaining the subjective results.

Table 4.9 presents all the significant other persons who participated in this study, including their relationship to the subject and the responses obtained in the open ended questions (questions: 1, 9, 12, 16, 18, 23 and 26) in the *Questionnaire for the significant other person* and in the semi-structured interview.

**Table 4.9: A presentation of the perceptions of the significant other persons**

<b>SUBJECTIVE OUTCOMES AS PERCEIVED BY THE SOP.</b>	
SOP=1	S=1 chose her mother as significant other person (SOP) to participate in this study. SOP=1 completed the <i>Questionnaire for the significant other person</i> and obtained a score of 61. This score indicated that SOP=1 was of the opinion that S=1 benefited from BCIs. SOP=1 indicated that the only soft sound that S=1 was unable to hear was the sound of raindrops falling on the roof. SOP=1 confirmed that it was her decision to apply for a second CI for S=1 as S=1 was under age (<18 years) at that time. In congruence with S=1's answer, SOP=1 indicated a positive change in the quality of S=1's relationship with her friends since receiving the second CI. Other noticeable differences included a change in hearing ability, improved self-esteem and self-confidence, better speech discrimination in noise, and perceptibly less anxiety and frustration. According to SOP=1, S=1 used an FM system that allowed her to hear speech at a constant level above the level of background noise, regardless of the distance of the speaker. SOP=1 stated that BCIs had altered S=1's life in such a way that she had an improved self-esteem that allowed her to engage more often in a conversation with strangers.
SOP=2	S=2 chose her companion as significant other person (SOP=2) to participate in this study. SOP=2 completed the <i>Questionnaire for the significant other person</i> and obtained a score of 57. This score indicated that SOP=2 was of the opinion that S=2 benefited from BCIs. SOP=2 also reported that S=2 could hear soft sounds <i>very well</i> without listing any examples. He indicated that it was the subject's own decision to apply for a second CI and that he had since noticed changes in her hearing ability and ability to understand speech in noise. Despite the positive changes, he conceded that she still avoided noisy settings such as shopping malls where many people and various sounds were overwhelming. He stated that since receiving a second CI S=2 was noticeably more at ease than before.
SOP=3	S=3 chose his wife as significant other person (SOP=3) to participate in this study. SOP=3 completed the <i>Questionnaire for the significant other person</i> and obtained a score of 57. This score indicated that the significant other person of the subject with BCIs was of the opinion that S=3 benefited

**Table 4.9: A presentation of the perception of the significant other person (continued)**

	<b>SIGNIFICANT OUTCOMES AS PERCEIVED BY THE SOP</b>
SOP=3	significantly from BCIs. Both subjects indicated that the softest sound that S=3 was unable to hear, was a whispering voice. She also confirmed an increase in S=3's annual income after he received a second CI and that it was their mutual decision to obtain a second CI. Furthermore she indicated that since receiving the second CI she had noticed positive changes in the quality of his relationship with friends and colleagues as well as changes in hearing ability, self-esteem and self-confidence, better speech discrimination in the presence of noise, and less anxiety and frustration. SOP=3 confirmed that S=3 avoided musicals, opera theatres, and watching television. If he ever did watch television, he watched sport programs with the sound turned off to avoid any frustration he might experience through not being able to hear the commentary. SOP=3 stated in conclusion that since he became a BCI user, S=3 had become more social.
SOP=4	S=4 chose his mother as significant other person (SOP=4) to participate in this study. SOP=4 completed the <i>Questionnaire for the significant other person</i> and obtained a score of 56. This score indicated that the significant other person of the subject with BCIs was of the opinion that S=3 benefited from BCIs. SOP=4 was unaware of the softest sounds that were inaudible to S=4. She confirmed that it was his own decision to apply for a second CI. SOP=4 reported that S=4 always had a good relationship with colleagues and friends with no change after he had received a second CI. The positive changes that she had noticed were with regards to his hearing ability, an improvement in his self-esteem and self-confidence, better speech discrimination in noise, and less anxiety and frustration. SOP=4 commented on S=4's reluctance to try to have a conversation on the telephone. She also commented on his dissatisfaction at work during the time this study ensued. She explained that he felt that although he had made a great effort to enhance his hearing ability he was still being discriminated against at work.
SOP=5	S=5 chose her mother as significant other person (SOP=5) to participate in this study. SOP=5 completed the <i>Questionnaire for the significant other</i>

**Table 4.9: A presentation of the perception of the significant other person (continued)**

	<b>SIGNIFICANT OUTCOMES AS PERCEIVED BY THE SOP</b>
SOP=5	<p><i>person</i> and obtained a score of 56. This score indicated that the significant other person of the subject with BCIs was of opinion that S=5 benefited from BCIs. SOP=5 did not know of any environmental sounds that were inaudible to her daughter. She conceded that S=5's income had not changed since she had received the second CI and that it was S=5's decision to apply for the second CI. SOP=5 indicated a positive change in the quality of S=5's relationships with colleagues and friends since she had received the second CI. Other positive changes included improvement in hearing ability, self-esteem and confidence, better speech discrimination in noise, and a reduced feeling of anxiety and frustration. SOP=5 indicated, without giving specific examples, that S=5 avoided going to places where she had difficulty hearing others. In general SOP=5 concluded that BCIs had altered her daughter's life in such a way that she had an improved self-esteem, the loudness of her voice was more controlled, and she resumed playing the piano. SOP=5 recommended BCIs for any approved candidate.</p>
SOP=6	<p>S=6 chose her companion as significant other person (SOP=6). SOP=6 obtained a score of 68 in the <i>Questionnaire for the significant other person</i>. This exceptionally high score indicated that SOP=6 was of the opinion that S=6 benefited greatly from BCIs. SOP=6 indicated that the softest sounds that S=6 was unable to hear included speech sounds such as the plosive [p] in the Afrikaans word 'pyp' and the plosive [b] in the Afrikaans word 'bril'. This was proved true when S=6 omitted the word 'bril' in her attempt to repeat a sentence in the speech discrimination test using sentences in a quiet environment. Although SOP=6 indicated a positive change in S=6's income since receiving her second CI, this was not indicated S=6's own questionnaire. SOP=6 confirmed that applying for a second CI was S=6's own decision and that he had since noticed positive changes in the quality of her relationships with friends and colleagues, as well as an improved ability to understand speech in the presence of noise. SOP=6 did not indicate situations that S=6 avoided. He stated that "BCIs are a true blessing".</p>

**Table 4.9: A presentation of the perception of the significant other persons (continued)**

	<b>SIGNIFICANT OUTCOMES AS PERCEIVED BY THE SOP</b>
SOP=7	S=7 chose her mother as significant other person (SOP=7) to participate in this study. SOP=7 completed the <i>Questionnaire for the significant other person</i> and obtained a score of 55. This score indicated that the significant other person of the subject with BCIs is of opinion that S=7 benefited from BCIs. SOP=7 was unaware of any soft sounds that S=7 had difficulty hearing. SOP=7 indicated that it was S=7's own decision to apply for the second CI as she had just turned eighteen during that time. SOP=7 indicated that since S=7's receiving the second CI she had noticed positive changes not only in the quality of her relationship with friends but also in hearing ability, better speech discrimination in noise, an improved self-esteem and self-confidence, and reduced feelings of anxiety and frustration. Furthermore she indicated that although S=7 did perceive the subjective benefits as mentioned, she still chose to avoid going to or attending group activities in noisy situations, as she found it difficult to function in those conditions. In general SOP=7 indicated that BCIs had altered S=7's life in such a way that she was able to attend and achieve Gr. 12 in a mainstream school. S=7 commented on this accomplishment and felt that BCIs granted her equal opportunities (compared to normal hearing peers) in life.

All the significant other persons (N=7) of the subjects with BCIs obtained scores above the baseline value in their questionnaire. This result indicated that all the significant other persons were of the opinion that the subjects with BCIs gained positive subjective outcomes with BCIs, especially in psychosocial factors related to QOL. These results also verified the subjects with BCIs' reported subjective outcomes.

The majority of the significant other persons' answers to the open-ended questions in the *Questionnaire for the significant other person* were consistent with the responses obtained from the subjects with BCIs. In some cases the answers were exactly the same, which verified those specific subjective outcomes. All the significant other people indicated that they had noticed definite changes in the

subject's ability to understand speech in noise after receiving the second CI. Six significant other persons indicated that they had noticed changes in hearing acuity and five significant other persons indicated definite positive changes in the subject's self-esteem and self-confidence as well as a reduced feeling of anxiety and frustration.

In addition, each significant other person gave an elaborated answer to the final open-ended question in the *Questionnaire for the significant other person*. The question required the significant other person to elaborate on all the noticeable changes in the subject with BCIs' life since receiving the second CI. Three significant other people elaborated on the subjects' improved self-esteem that allowed them to engage more easily in conversation with strangers, and participate in more social activities with less reluctance. One significant other person stated that BCIs had made the subject more at ease than before. It was revealed that this particular subject had been a victim of crime and that her significant other's statement viz. "feels more at ease" referred to the subject's awareness of her surroundings and personal safety. A different significant other person (SOP=7) indicated that BCIs had altered the subject's life in such a way that the subject was able to attend and achieve Gr. 12 in a mainstream school and because of that accomplishment she felt that BCIs granted her equal opportunities (compared to peers with normal hearing) in life. Another positive remark was made by one significant other person who simply wrote: "BCIs are a true blessing". One significant other person felt compelled to report that although she acknowledged the benefits her son perceived with BCIs, she knew that he was dissatisfied at work and that he felt that although his hearing ability had improved, he was still being discriminated against at work. The information revealed by the significant other persons not only attested to the inclusion and importance of the significant other persons' role in this study, but also emphasized the importance of investigating whether the presumed audiometric benefits were perceived by the subject in other domains related to her / his quality of life. Sub-aim four and five were expediently set to identify any correlation between the objective and subjective outcomes of the subjects with BCIs. The results pertaining to the fourth sub-aim, viz. 'to investigate the correlation between the objective and subjective outcomes of each subject with BCIs individually' are presented and described concurrently with this study's final

sub-aim: 'to investigate the correlation between the objective outcomes and subjective outcomes as perceived by the significant other person.'

**4.5 SUB-AIM 4: To determine the correlation between the objective outcomes and subjective outcomes of each subject with BCIs individually and**

**4.6 SUB-AIM 5: To determine the correlation between the objective outcomes and subjective outcomes as perceived by the significant other person**

The rationale for the inclusion of these sub-aims derived from the researcher's awareness that the benefits of BCIs, as perceived by the user in everyday situations, remain the most valuable data in verifying the objective outcomes and perhaps also in validating the merit of BCIs as intervention type. In an attempt to investigate whether a correlation existed between the subjective and objective outcomes, the researcher evaluated and compared each subject's objective outcomes with his / her subjective outcomes as perceived by the subject and according to her / his significant other person.

As all the subjects with BCIs obtained significant audiometric results with BCIs and also obtained scores above the baseline value in the *Questionnaire for the subject with BCIs*, a positive correlation was revealed between the objective and subjective outcomes of each subject. Furthermore, as all the subjects (subjects with BCIs and their significant other persons) achieved scores above the baseline values set in their respective questionnaires, a positive correlation was found between the BCI-users' objective outcomes and their reported subjective outcomes as perceived by the subject with BCIs and their significant other person.

Each subject's subjective data, as revealed by the BCI user and her / his significant other person in their respective questionnaires and the semi-structured interview were viewed, and compared to that subject's individual performance in the audiometric assessments. In addition to significant audiometric findings in the various tests included in the audiometric test battery, the subjects with BCIs and their significant others reported benefits perceived in everyday listening conditions that were consistent with and verified the objective outcomes. The main

correlations between the objective and subjective outcomes of the subjects with BCIs are discussed according to the audiometric findings.

#### 4.6.1 Improved hearing sensitivity

Two subjects achieved puretone averages of 20 dB HL, which, according to Jerger (1980, in Hall & Mueller, 1997:104), is indicative of normal hearing in an adult. The remaining five subjects with BCIs obtained average puretone thresholds between 20 and 40 dB HL which, according to Jerger (1980, in Hall & Mueller, 1997:104), is indicative of a mild hearing loss. Considering the subjects' degree of hearing loss without amplification or prior to receiving their first cochlear implant, namely severe-to-profound hearing loss, a mild hearing loss is indicative of improved hearing sensitivity with BCIs and thus indicative of a positive objective outcome with BCIs. Subjectively, all the subjects with BCIs and their significant other persons reported an enhanced ability to hear not only the speech of others but daily environmental sounds as well since receiving the second CI. In this study, a correlation was found between the objective and subjective measurements regarding hearing sensitivity. Upon viewing the subjects' unaided audiograms prior to receiving their first cochlear implant (received from the PCIP) all the subjects' auditory thresholds had improved with bilateral implants, and the majority of the subjects indicated an increase in perceptual loudness in everyday listening situations. According to Litovsky (2008:4) an increase in perceptual loudness can also contribute to the subjects' ability to perform speech recognition in noise tasks, which was also investigated in this study.

#### 4.6.2 Improved ability to discriminate speech in noise

All the subjects with BCIs were able to discriminate speech (words and sentences) in the presence of interfering background noise. Three subjects were able to discriminate between words and sentences when the signal was presented at 60 dB SPL and the noise level was presented at 50 dB SPL, a SNR of +10 dB. The remaining and majority of the subjects (N=4) experienced discomfort and a reduced ability to discriminate between words at the predetermined intensity levels where testing commenced, and asked that the noise level be reduced. The researcher complied with the subjects' request and continued the speech discrimination testing



at a speech signal of 60 dB SPL while competing noise was simultaneously presented at a 45 dB SPL. These four subjects were able to discriminate words in noise at a SNR of +15 dB. Subjectively, the majority of the subjects (N=6) reported an improved ability to discriminate speech in noise since receiving the second CI. One subject, S=7, did not indicate an improved ability to discriminate speech in noise. This subjective benefit was, however, reported by her significant other person, SOP=7.

As the subjects' ability to discriminate speech using open set speech discrimination tests were objectively determined and their ability to discriminate speech in everyday listening situations was subjectively reported, a correlation was found between the objective and subjective outcomes with regards to speech discrimination in noise.

#### 4.6.3 Improved localization acuity

Although all the subjects with BCIs were able to localize the sound source from the frontal and posterior hemi-field when the sound was presented separately, only two subjects were able to localize sounds when presented binaurally from behind. Considering that the objective localization testing was conducted in a sound proof room, the results could be compared to the subjects' perception of their ability to localize the sound source in a quiet environment. The majority of the subjects (N=4) indicated that they were *usually* able to localize the source of a sound in a quiet environment. Two subjects indicated that they were *sometimes* able to, and one subject indicated that she was *often* able to localize the source of a sound in a quiet environment. The subjective reports supported the objective findings that some aspects of the ability to localize sounds in space in a quiet environment that were not yet restored with BCIs.

#### 4.6.4 Improved binaural hearing

Binaural hearing is the phenomenon that allows normal hearing individuals to understand speech in noisy situations, to localize sound sources, and to facilitate listening in conversations from either side with equal clarity. As all the subjects with BCIs obtained significant objective outcomes that in some cases compared to the

hearing acuity of individuals with normal hearing, the current researcher was of the opinion that more subjective reports indicative of binaural hearing would be revealed. Subjective reports indicative of binaural hearing were revealed in S=1's subjective ability to follow what was being said when having a telephone conversation and someone next to her started talking, and in her ability to listen to the teacher by means of her FM-system with one ear while being able to hear what her friends in class were saying to each other. This could also be indicative of the binaural squelch effect, which allows the brain to separate signals from noise coming from different directions, by comparing time, intensity, and pitch differences between the two ears (Litovsky, 2008:4). Another subjective report indicative of binaural hearing was revealed by S=2, who stated that she hears 50% less with one CI than with BCIs. This could be indicative of the binaural summation / redundancy effect, which enables a person to perceive a sound that is heard binaurally to be twice as loud as one heard monaurally, and the hearing sensitivity of the person to hear small increases in intensity and frequency. A different subject indicated that she found the tasks that previously required intense attention and concentration less tiring than before receiving the second CI. Poor hearing jeopardizes a person's ability to concentrate and conscious effort is required to maintain attention, which in turn causes fatigue (Hicks & Tharpe, 2002:573). This subjective outcome is indicative of a perceived improvement in hearing acuity that can be related to the binaural summation / redundancy effect.

The subjects' perception that their improved auditory abilities allowed them to be more participative in social events pointed to awareness of their improved hearing acuity in everyday listening conditions. The responses obtained in the open-ended questions revealed that the majority of the subjects (N=5) were of the opinion that BCIs contributed to changes in domains related to QOL and that significant subjective benefits were perceived in everyday listening tasks since they had received the second CI. On the other hand, the remaining two subjects with BCIs reported that although they acknowledged the significance of the outcomes of BCIs, they were unconvinced that BCIs directly contributed towards changes in quality of life.

The researcher predicted that the correlation between the objective and subjective outcomes of BCIs may be more significant for some subjects than for others, especially because the subjects were asked to state their own definition of the term 'quality of life', based on their personal beliefs and prospects. For S=2, the term 'quality of life' included being able to communicate effectively with others and being able to feel at ease and safe. S=2 was unconvinced that BCIs directly contributed to her communication or safety. S=2 explained that to communicate with others she mainly used electronic mailing, which did not require fine hearing, and that her safety had recently been jeopardized by a traumatic hijacking incident. For S=5, the term 'quality of life' dealt with a person's striving to do the best he / she can do in everything he / she attempts. She explained that a person's QOL can be measured by comparing a person's accomplishments with what the person had planned to accomplish with that particular event or situation. S=5 was unconvinced that a second CI had a direct impact on her ability to achieve the goals she had set for herself.

Finally, SOP=4 revealed significant information about S=4's dissatisfaction at work. According to SOP=4, S=4 felt that although his hearing had improved with the addition of a second CI, he was uncertain whether improved hearing acuity could grant him equal opportunities for employment and still felt that he was being discriminated against. As a result, this was not considered a correlation, as the positive objective outcomes revealed in the audiometric assessments did not correspond with his expectations, goals and perception of himself in his work environment. In contrast S=3 and his significant other indicated an improvement in his annual income since he received his second CI and S=6, who had to participate in several work-related meetings, indicated that she perceived her work to be less tiring and to require less concentration since receiving the second CI.

In this study, the majority of subjects (N=4) were employed and capable of earning a taxable income. One subject was retired at the time of this study and the remaining two subjects were in their final year of school. A study conducted by Hogan, Stewart and Giles (2002:54) investigated the employment experiences of people with a cochlear implant. They found that following implantation, working life was markedly better for cochlear implant users. Their subjects reported being able

to pursue the jobs they were trained for with greater confidence and also reported a greatly enhanced sense of job security. Most notable in their findings was that the CI users felt able to take career risks such as seeking out better employment opportunities. In their study the respondents also noted that the post-implant transition back to work could be made simpler for cochlear implant recipients if appropriate vocational services were offered as part of their rehabilitation program. If these services are not already offered, the latter recommendation is perhaps worth considering for the subjects in the PCIP. This is based on the fact that BCIs can provide recipients with increased opportunity for education and employment.

#### **4.7 Conclusion to Chapter 4**

The conclusion of chapter 4 is that bilateral cochlear implantation is advantageous for all the subjects who participated in this study. Current cochlear implant technology enables BCI-users not only to obtain significant objective outcomes, as was determined in a controlled environment, but also to perceive and enjoy the advancements in everyday listening conditions. This conclusion was based on the comprehensive assessment of each subject's objective outcomes as well as her / his subjective outcomes as perceived by the subject with BCIs and by a significant other person. All the significant other persons acknowledged definite improvements in the subjects with BCIs' ability to discriminate speech in noisy conditions, which probably represents the most significant outcome revealed in this study. Some changes in domains related to the quality of the subjects' lives were also revealed in reported improvements in the subjects' self-esteem and self-confidence as a result of the subjects' perception of the improvements in hearing acuity. The majority of the subjects in this study noticed an improvement in the enjoyment of music, and they were also able to have a more clear and enjoyable telephone conversation since receiving the second CI. Overall, the subjective outcomes as reported by the subjects with BCI's and their significant other persons were consistent with the objective outcomes in both prelingually and postlingually deafened adults.

It has been said that two of the greatest challenges facing cochlear implant professionals are finding pre-implant predictors of post-implant performance, and finding ways to improve performance for individual cochlear implant users (ASHA,

2004:2). The current researcher is of the opinion that the results found in this study could provide future bilateral cochlear implant candidates with comprehensive information regarding the outcomes of BCIs in adults. The results of the current study are in agreement with those of Firszt, Reeder and Skinner (2008:750) and Peters (2006:4), who also found the clinical scores obtained in their study to be supported by their subjects with BCIs' subjective experiences.

#### **4.8 Summary**

Chapter 4 presents a detailed discussion of the results of this study. The most significant findings of the study were revealed in the objective and subjective measurements related to the subjects with BCIs ability to discriminate speech in noise and, to some extent, to localize sounds in space. These findings were in accordance with previous research findings which validate the most significant outcomes of BCIs in adults with current cochlear implant technology. The results obtained in this study also indicated that the benefits perceived by the subjects with BCIs and by the significant others were not only related to improvements in communication activities but especially related to psychosocial factors that exerted a positive influence on the majority of the subjects' QOL.

## **CHAPTER 5**

### **CONCLUSIONS AND RECOMMENDATIONS**

The conclusions from the results for each sub-aim and ultimately the main aim are provided in Chapter 5. The implications of the findings for the field of Audiology are discussed and recommendations for future research, some of which derived from a critical evaluation of this research project, are made.

#### **5.1 Introduction:**

Previous research on BCIs documented certain benefits which made it possible for the researcher to project certain expectations. Although previous studies utilised diverse procedures to evaluate the outcomes of BCIs, the majority of the studies found evidence of binaural hearing related to an improved ability to understand speech in the presence of noise and an improvement in the ability to localize sound (MED-EL, 2003, retrieved from their website on May 22, 2007). Accordingly, the current researcher decided to use various assessment methods including objective measurements and subjective information to determine the outcomes of BCIs. The small number of subjects who participated in this study (N=7), facilitated the appraisal of the effectiveness of the assessment methods.

Preceding studies also provided the researcher with information on certain variables, such as the BCI users' experience with binaural hearing, that might offer some advantages on functional tasks and have an effect on the outcomes. Litovsky (2004:648) commented that it was difficult to ascertain the extent of the advantage after only three months of bilateral listening experience and recommended that future research call for a more prolonged period of adjustment to listening with BCIs. Based on this recommendation, the selection criteria in this study included the subject with BCIs should have been implanted with their second implant for a period of at least six months post-implantation for the second cochlear implant. At the time of the current study, all the subjects with BCIs had received their second cochlear implant at least one year previously. Given the subjects' extensive experience with binaural hearing, it was predicted that the results obtained in the various assessment methods would correspond and ultimately confirm the reliability of the outcomes

## **5.2 Overview of the main findings of the study**

The data collection instruments and apparatus used in this study were designed to determine the ability of BCI users to use both devices in a controlled environment as well as to monitor the outcomes as perceived in everyday, complex listening conditions. For this purpose, all the audiometric assessments performed in this study investigated the single aspect of binaural hearing with both CIs switched on the regular setting. The subjects were also asked to reflect mainly on their listening experience with BCIs when answering the questions in the questionnaires and interview, unless a question specified otherwise.

This study therefore concerned itself with investigating the outcomes of listening with an alternative means of binaural stimulation, viz. bilateral cochlear implants. In normal hearing listeners, binaural hearing is known to be beneficial for sound localization and speech discrimination in noise. Numerous studies on BCIs have concurred that the two main advantages of BCIs are the potential to improve speech discrimination abilities in quiet conditions and in the presence of interfering noise, and the ability to localize sounds in space (Litovsky et al., 2004; Peters, 2006; Brown et al., 2007).

The results of this study suggest that, in adults, subjects with BCIs show definite abilities to discriminate speech in the presence of competing noise. The ability to understand speech in more complex acoustic environments was demonstrated by objective measurement and subjectively reported by the majority of the subjects with BCIs and their significant other persons. Definite advantages in the subjects with BCIs' ability to localize the source of sound were also revealed. On the grounds of an overview of the main results of this study, the researcher came to the following conclusions.

## **5.3 Conclusions**

The conclusions of this study are discussed according to the sub-aims laid out in the methodology section of this study.

### **5.3.1 Conclusions relating to sub-aim 1**

Sub-aim 1 investigated the objective outcomes of adults with bilateral cochlear implants. In this study the pure tone thresholds (PTA's) of the majority of subjects (N=5) with BCIs were determined at an average intensity indicative of a mild hearing loss. According to a classification of hearing impairment severity by Jerger (1980, in Hall & Mueller, 1997:104), the threshold levels associated with a mild degree of hearing loss are 21 to 40 dB HL. Remarkably, two subjects with BCIs were able to obtain PTA's at 20 dB HL. According to Jerger (1980, in Hall & Mueller, 1997:104) PTA's at 20 dB HL are indicative of normal hearing in an adult.

The findings in the speech discrimination tests using words and sentences revealed that all seven subjects were able to discriminate between monosyllabic single words and between key words when presented in sentences at a typical normal conversational level (Katz, 2002:105). With regard to the subjects' ability to discriminate speech in the presence of interfering noise, three subjects were able to discriminate speech at a SNR of +10dB and the remaining four subjects were able to discriminate speech in noise at +15dB SNR. According to Katz (2003:608), individuals with a SNHL require +4 to +12 dB SNRs to obtain scores comparable to normal hearing listeners.

All the subjects in this study were able to localize speech noise presented at ear level from 45°, 135°, 225°, and 315° angles. On the other hand, fewer subjects (N=5) with BCIs were able to localize the sound source when presented from 45°+135° simultaneously and only two subjects were able to localize the sound source when presented in the posterior hemi-field from 225°+315° simultaneously. Although the majority of subjects were able to localize the sound source when presented separately, the subjects' inferior ability to localize the sound source when presented binaurally may suggest that sound localization acuity with BCIs is not yet fully restored.

### **5.3.2 Conclusions relating to sub-aim 2**

Sub-aim 2 investigated the self-reported or perceived subjective outcomes of the subjects with BCIs. Their perception with regard to subjective benefits in



communication activities, contextual factors, and psychosocial issues were revealed. The majority of the subjects with BCIs indicated that they perceived positive subjective outcomes with BCIs in everyday listening conditions. All the subjective outcomes as perceived by the BCI users in everyday listening conditions are listed and briefly explained below:

- Improved speech discrimination: Six subjects reported improved understanding of speech in the presence of noise. It is generally known that binaural hearing helps normal hearing individuals to differentiate individual voices and separate speech from competing noise. As all the subjects with BCIs were able to discriminate speech in the presence of interfering noise and the majority of subjects reported an improved ability to discriminate speech in everyday listening conditions since receiving the second CI, this finding and subjective outcome demonstrate the perceived benefit of the second cochlear implant and possibly the head shadow effect.
- Wider hearing range: All the subjects reported that since receiving the second CI, they are able to hear sounds, which were previously barely audible with one cochlear implant, with more ease and over an extended distance.
- Listening: Four of the seven subjects indicated that they experience listening with BCIs to be less tiring and that it requires less concentration than listening with one cochlear implant that was physically tiring and stressful at times.
- More natural tone quality: Five subjects reported that with BCIs the quality of sounds, especially human voices and music, seems to be more natural than with one cochlear implant. These five subjects reported that they enjoy listening to music more since receiving the second CI.
- Localization acuity: During the objective testing, the majority of subjects were able to accurately localize the sound source from the frontal and posterior hemi-field when the sound was presented separately; fewer subjects were able to localize the sound source when sound was presented binaurally. Five subjects were able to localize the sound source when sound was presented binaurally / simultaneously from the front and only two subjects were able to localize the

sound source when sound was presented binaurally / simultaneously from behind. Despite the objective outcomes found in the localization testing, the majority of subjects indicated that although they are *usually* (N=4) able to locate the source of sound in a quiet listening situation they are only *sometimes* (N=4) able to locate the source of a sound when in an unfamiliar listening situation and when in a noisy listening situation. It is important to consider, however, that the subjects may not realize that their improved speech discrimination ability in less favourable signal-to-noise ratios could be the result of subconscious head positioning, a propensity indicative of improved localization acuity.

- **Speechreading:** Another interesting subjective finding was one related to speechreading. All the subjects with BCIs indicated that they were able to obtain additional information regarding the spoken message through speechreading. Two subjects indicated that their competency in speechreading had increased since receiving the second CI. Three subjects indicated no change in their ability to speechread and two subjects indicated a decrease in their ability to speechread since receiving the second CI as the need for speechreading decreased with enhanced hearing acuity. Speechreading is usually learnt (either formally taught or self-acquired) as a compensatory strategy in the presence of hearing loss, in order to better understand speech. The researcher had expected more subjects to report a decrease in their ability to speechread after receiving the second CI. This expectation was based on the subjects' improved hearing acuity that should reduce the need to rely on speechreading.
- **Volume of own voice:** Two subjects reported that their own voices seemed less loud as perceived with BCIs than as perceived just before receiving the second CI. This subjective outcome is indicative of the subjects' increase in hearing aptitude.
- **Better performing ear:** A few subjects reported that with a second cochlear implant, the fact that both ears are implanted allows the user to identify a "better performing" ear. If, for some reason, one cochlear implant should be unsuccessful or the device should fail, the person still has the alternative to use the other device. Candidates, struggling to meet the expenses to attain their first CI, might not even want to consider this eventuality.

- Self-esteem and self-confidence: The majority of subjects with BCIs indicated that as a result of the outcomes of BCIs, they experience enhanced self-esteem and a feeling of self-confidence that allows them to engage more freely in social and cultural activities.
- Anxiety and frustration: It is interesting to note that the minority of subjects indicated a reduced feeling of anxiety and frustration as a result of BCIs. It is important to consider that this finding could suggest that the majority of subjects never felt anxious or frustrated with a monaural cochlear implant and therefore could not indicate a feeling of reduced anxiety or frustration since receiving the second CI. On the other hand it is possible that the second cochlear implant did not reduce the feeling of anxiety or frustration that they had before.
- Quality of life: The majority of subjects (N=6) indicated that BCIs contribute positively to domains that affect the quality of their lives. It was revealed that the perceived benefits of BCIs endow the user with an enhanced self-esteem and feeling of self-confidence that enliven and improve her / his communication skills, and provide the user with internal advocacy to be more participative in social, cultural and environmental contexts. This remarkable subjective outcome was not only perceived by the subject but also acknowledged by her / his significant other person.
- Binaural hearing: Three subjects reported improvements in binaural hearing ability that were possibly related to the head shadow effect. There appears to be fewer benefits associated with the binaural summation and the binaural squelch effect. Other studies also find the reduction of the head shadow effect more evident than the squelch or the summation effects (Peters, 2006:3; Tyler, Dunn, Witt & Preece, 2003:392).

In summary, the self-reported subjective outcomes indicated definite improvement in hearing acuity and speech discrimination in noise ability, as well as some improvement in the subjects' ability to localize the source of sound in quiet, unfamiliar and noisy listening situations since receiving the second CI. For most subjects, the mentioned advantages perceived with BCIs enable them to be more

participative and communicative in social and cultural activities, with more self-confidence. The majority of the subjects indicated that BCIs had altered their lives and contributed this transformation to changes in domains related to the quality of their lives. The majority of subjects agreed that the benefits of BCIs merit the expenses and indicated that, if they had to decide again, they would undoubtedly make the same decision to attain the second CI, perchance even sooner.

Some subjects also reported an enhanced self-esteem and reduced feeling of anxiety and frustration. In addition, some subjects were also able to enjoy the marvel of listening to music and to have a clearer conversation on the telephone after receiving the second cochlear implant. The results from this study also indicated that the addition of a second CI has the potential to reduce the subjects' reliance on speechreading as a function of improved hearing acuity. For some, the improvement in hearing acuity resulted not only in an improvement in the perception of environmental sounds but also in the spatial separation of sounds which aided in controlling the volume of their own voice. On the whole, the majority of the subjects with BCIs perceived positive subjective outcomes.

### **5.3.3 Conclusions relating to sub-aim 3**

The third sub aim, to determine the subjective outcomes of BCIs as perceived by a significant other of the subjects with BCIs, was included to monitor the perceptions of the subject with BCIs perceptions by comparing them to a significant other person's point of view. All the perceptions of the significant other persons were in accordance with the subjective outcomes as perceived by the subjects with BCIs in daily listening situations. All the significant other persons indicated that they had noticed that the subjects with BCIs were able to hear better and understand speech better in various and sometimes challenging listening situations. All the significant other persons also indicated noticing an increase in the subjects with BCIs' self-esteem and self-confidence that enabled them to engage more freely in social activities. For some, reduced feelings of anxiety and frustration were also evident. In addition, the remarks made by the significant other persons suggested definite changes in domains related to the subjects with BCIs' quality of life. This was

revealed in statements reflecting positive changes in family dynamics and other emotional, social, psychological, and cultural domains.

#### **5.3.4 Conclusions relating to sub-aims 4 and 5**

To achieve this study's fourth and final sub-aim, viz. to investigate the correlation between the objective and subjective outcomes of each subject with BCIs individually and the outcomes as perceived by the significant other, the subjective outcomes were compared to the objective outcomes of the audiometric tests. The reported subjective experiences of all the subjects with BCIs in this study were consistent with the results from the audiometric tests. Together, the objective and subjective results overwhelmingly support bilateral implantation in both the prelingually and postlingually implanted individuals who participated in this study.

As both the audiometric and the subjective assessments revealed positive results, a confirmatory correlation exists between the objective and subjective outcomes of subjects with BCIs. The most significant correlation was that between the subjects' objective outcomes as determined by the results of the speech discrimination tests and their subjective perception of their enhanced ability to discriminate speech in more complex acoustic environments. The majority of subjects revealed that since receiving the second CI, they have become more participative and felt more confident participating in a conversation with a group of people.

A second correlation was found between the subjects' ability to objectively locate a sound source when presented from six different locations throughout the full 360° azimuth in the horizontal plane, and their subjective experience of this skill in daily listening situations. Although this ability had not improved to the same degree as revealed in the subjects' speech discrimination ability, the majority of the subjects were able to locate the sound source from five different angles during objective testing, and reported some subjectively experienced improvement in their ability to locate the source of sounds in everyday listening conditions. It is generally known that one of the main challenges experienced by a person with a unilateral hearing loss often experience is the inability to locate sounds.

Lastly, a correlation between the objective and subjective outcomes was also determined in the subjects' ability to perform tasks that required binaural hearing. The majority of the subjects were able to perform the speech in noise tasks and proved localization acuity when the sound was presented from five different locations throughout the full 360°, which is evident of the head shadow effect due to binaural hearing. Subjectively the perception of this binaural mechanism was revealed in the subjects' statements regarding an improved ability to follow the speech of two people simultaneously; an enhanced ability to follow the proceedings in a meeting as it requires less concentration than before and the perception of an increase in hearing sensitivity with two CIs. The reduction of the head shadow effect appears to be the most consistently beneficial binaural outcome for adult cochlear implant users, with some evidence of the binaural squelch and summation effects. In conclusion it is evident that a correlation between the objective and subjective outcomes of adults with BCIs was determined.

#### **5.4. Conclusions with regard to the main aim of this study.**

The main aim of this study was to investigate the objective and subjective outcomes of BCIs in adults. In an attempt to achieve the main aim, five sub-aims were formulated and successfully accomplished. In this study, adults with BCIs benefited from positive outcomes according to both objective and subjective measures. In support of this finding, the significant other persons of the subjects with BCIs confirmed the subjective outcomes reported by the subjects with BCIs and agreed that the subjects with BCIs benefit from BCIs in everyday listening conditions. Ultimately, the subjective outcomes of BCIs were consistent with the objective outcomes, which suggested a positive correlation that verified the outcomes. It was therefore demonstrated clearly that the positive outcomes of BCIs are perceived in daily listening conditions which contribute to changes in domains related to the improvement of the quality of life of the adults with BCIs.

#### **5.5 Implications of the findings**

Worldwide, the current intervention strategy of choice to ensure high quality hearing for people with severe-to-profound hearing loss is a cochlear implant and more specifically bilateral cochlear implants. Cochlear implant technology has developed

consistently and rapidly since devices with multiple electrodes first came into widespread use almost 30 years ago. Advances have occurred, and are continuing to occur, in many aspects of cochlear implant design and application. With further advances in cochlear implant technology, the selection criteria of the different cochlear implant programs have become more relaxed and currently allow a more diverse population with hearing loss for candidacy. Considering the wide range of outcomes that may emerge, this study investigated the objective and subjective outcomes of adults with bilateral cochlear implants in the Pretoria Cochlear Implant Program. The assessment of each individual with BCIs was essential to determine the efficacy of the intervention type and corroborate the program's selection criteria.

In accordance with findings of other studies, this study's objective measures found BCIs to improve the adult users' hearing aptitude and give them the perception of sound being "fuller", more balanced and of a better quality (MED-EL 2003). All the BCI users were able to perform speech discrimination tasks in the presence of noise and to locate the source of sounds when the sounds were presented separately. As a result of the objective outcomes, the adults in this study also reported subjective outcomes that enhance their psychosocial well being. Some, BCI users reported a feeling of enhanced self-esteem and self-confidence, as well as improved communication in a variety of contexts and for some, an improved ability to enjoy the marvel of listening to music and having a conversation on the telephone. Together, these outcomes enable the adult BCI users to be socially and culturally more participative. It is evident that BCIs contribute to changes in domains related to the improvement of the quality of life of the adults with BCIs. This study also found bilateral cochlear implants to be a safe (no reported surgical risks), beneficial (in both objective and subjective measures) and highly recommended (by BCI users and their significant other persons) intervention strategy. The results from this study also suggested that BCIs may provide the adult recipient with binaural cues that allow the user to better understand and discriminate speech as well as to locate the source of sounds in space. As all the results from the objective assessments were verified by consistent subjective reports, triangulation of the results occurred that confirmed the significance of the outcomes.

Despite the positive outcomes adults perceive with BCIs, BCIs are not considered to be a “cure” for deafness, but rather an exceptional means of providing individuals with severe-to-profound hearing loss, with the probable sensation of binaural hearing. The data obtained in this study support the theory that the benefits of bilateral cochlear implants significantly outweigh the risks, and that BCIs can be considered an appropriate treatment for people with severe-to-profound hearing loss. Considering the dynamic field of Audiology, more options are likely to occur with future advancements in technology concerned with amplification. Until then, bilateral cochlear implants are considered to be the best intervention option (Tyler, Dunn, Witt & Preece, 2003:392).

### **5.6 Critical evaluation of this research project**

This study proposed to investigate the outcomes of BCIs in adults. This goal was successfully achieved and the research question was answered by using a reliable and valid methodological procedure. Comprehensive procedures were applied in search of each subject’s objective and subjective outcomes with BCIs. Ultimately, triangulation demonstrated that the results from different assessment procedures complemented each other and thereby provided a way to answer the research question. To define the significance and utility of the outcomes, the researcher conducted an appraisal of the strengths and limitations that became apparent during the course of this study. This section critically reviews and discusses some of the identified particulars.

- Although the comprehensive assessment procedure allowed for an in-depth analysis of each subject in this study, this study should optimally have included all the adult BCI users from the different cochlear implant programs in South Africa. In this manner, the results from the study could have been generalized to all the adults with BCIs living in South Africa.
- The tasks used in this study were designed to determine the ability of BCI users to use both ears when functioning in complex, multi-source everyday listening environments. For this purpose the audiometric assessments performed in this study focused on the investigation of binaural hearing with both CIs switched on the regular setting. Another investigation that could have been included in this



study is the subjects` performance with a unilateral cochlear implant and the comparison of these results to the results obtained with BCIs. It is generally known that unilateral cochlear implant users perform better under quiet conditions than when exposed to noise, and that they require better signal-to-noise ratios for effective communication than do individuals with normal hearing or, as in this case, their counterparts with BCIs. As comparative investigation was not included in this study, the findings concerning *improvements* with BCIs as opposed to listening with monaural CIs are based solely on the subjective reports by the subjects with BCIs and their significant other persons.

- Although the localization test produced positive results, the simplicity of the test did not allow for a broader ranging conclusion. The localization test should optimally have included more loudspeakers from which different stimuli could have been presented in the 360° azimuth on the horizontal plane. Future studies may consider using different types of stimuli that may represent everyday sounds such as the loud wailing sound of sirens or the high pitched hooting sound made by a vehicle's horn, the rumbling sound of thunder and perhaps the sound of a distant conversation between people. The ability to identify and locate different types of sounds, especially warning sounds, is important in order to avoid potentially dangerous situations (i.e. a fire engine speeding down the street), and to provide subtle cues for speech recognition.
- Lastly, this study requested the subjects to indicate whether they had made use of bimodal amplification before receiving the second CI. According to Peters (2006:3), all unilateral cochlear implant recipients should first utilize a hearing aid on their non-implanted ear if the residual hearing in that ear is capable of providing a binaural advantage. Research has shown that individuals can combine and use acoustic stimuli from one ear and electrical stimulation from the other ear to obtain bilateral hearing effects that include enhanced speech understanding and localization abilities (Ching, Psarros, Hill, Dillon & Incerti, 2001, in Dunn, Tyler & Witt, 2005:669; Ching et al., 2009:26). Although the subjects who had made use of HA amplification prior to receiving the first and / or second CI were identified, the influence of the bimodal input on their current performance with BCIs, was not examined.

## **5.7 Recommendations for further research**

The findings of this study seem to suggest that CI-users, clinicians, researchers and CI manufacturers should continue to work together towards a goal of improving the quality of life of the subjects with hearing loss and continue to focus on amplifying both ears, especially with bilateral cochlear implants. Future studies need to explore the incremental benefit of BCIs compared to unilateral implants for speech discrimination in quiet and in noise, sound localization, speech detection, and in particular the outcomes identified in changes in domains related to quality of life. Future studies that determine the incremental benefit of BCIs compared to unilateral implants may be able to ascertain whether or not the benefits that BCIs offer are outweighed by the increased cost. The investigation could include the differential analysis between simultaneous implantation (a procedure still rare in South Africa) and sequential implantation. It has been suggested that simultaneous implantation may be more cost effective than sequential bilateral cochlear implantation, since it will eliminate additional hospitalization costs, mapping sessions, etc. The benefit of the sequential approach is that it allows the patient to continue using a hearing aid in the non-implanted ear for later determination of bimodal benefit before committing the second ear to implantation. In South Africa, a third world country with a vigorous economy, the analysis of the cost-effectiveness of a second cochlear implant is justified.

In South Africa, the government does not provide funding or contribute towards a cochlear implant. Although an estimate 20,1% of the total South African population has some degree of hearing loss (Statistics South Africa, Census 2001, accessed February 21, 2009) cochlear implants are still considered a low priority when expenditure on intervention are set. Consequently, the majority of patients that apply for a cochlear implant have to rely on other means of financial support, often the private health sector which is financed by the medical aid industry. At the current time only 16% of the South African population has medical aid coverage, while the public sector is responsible for 84% of the population. It is clear that a large number of people with hearing loss in South Africa may not have the resources to be able to obtain a cochlear implant as intervention strategy.

A further recommendation for future studies is to continue investigating and to refine the assessment of BCI users' localization acuity. Localization is an important element of listening that allows the listener to identify and focus on the source of sound. Although it seems as though current technology offers CI users the opportunity to take advantage of the head-shadow effect, the extent to which binaural cues are available to listeners with BCIs is not yet well understood. This was revealed in the sound localization test that proved that subjects with BCIs are capable of locating sounds presented on their horizontal plane but not sounds presented binaurally. Given the high likelihood that among BCI users there are differences between the two ears with regard to electrode placement, neural survival, and mapping, it is evident that without enforcing synchronization between the two devices, the subjects' use of true binaural stimuli will remain imperfect. As scientific research and CI device technology continues to improve, benefits related to the effects of binaural hearing are likely to become more apparent. In addition, future technology may be expected to improve faithful replication of inter-aural cues and build upon the current success related to binaural hearing. In turn, further advancements in technology and objective outcomes may add to the perceptual correlate of binaural hearing in everyday listening conditions. It is thus recommended that future studies continue to investigate the outcomes related to the binaural cues, i.e. speech discrimination and localization acuity, as the outcomes are likely to change as technology augments.

It is also recommended that future studies investigate the differences in performance of BCI users with a history of hearing aid use, as well as the differences in performance of BCI users with a pre-lingual and post-lingual onset of deafness. It is generally thought that adults with a post-lingual onset of deafness have better outcomes than adults with a history of pre-lingual onset of deafness or adults who were born deaf. This is due to the neural patterns laid down in the early years of life which are crucially important for speech perception. This study did not include a comparison between subjects. As a result, the differences (if any) in performance between the prelingually deafened adults, who were fewer in number, and their postlingually deafened counterparts were not investigated. This study could have investigated the differences in performance more thoroughly in order to

provide all potential candidates (both postlingually and prelingually deafened adults) with more specific expected outcomes related to the onset of their hearing loss.

## **5.8 Conclusion to Chapter five**

The outcomes of bilateral cochlear implantation in adult recipients, as determined in this study, may enable any cochlear implant team and potential candidate to better understand and implement the outcomes of bilateral implant use. Although a small number of subjects participated in this study (N=7), the extensiveness of the investigation of each subject individually allowed for an in-depth discussion of the outcomes of each subject with BCIs who participated. The results of the study are considered to be a reliable reflection of the perceptions of these subjects and their significant other persons. This was based on the triangulation of results that occurred and the verification of the objective outcomes by both the subject with BCIs and the significant other people in their consistent subjective reports. The favourable objective outcomes of BCIs in adults were consistent with the subjective experiences of the subjects in everyday listening conditions. All the subjective reports overwhelmingly favoured bilateral cochlear implantation in both prelingually and postlingually deafened adults. The results of this research study will enable the PCIP to make evidence-based recommendations, and potential candidates to make informed decisions when considering a second cochlear implant. Based on the positive subjective and objective outcomes found in this study, the significance of binaural hearing is incontrovertible and the provision thereof through BCIs should be considered the standard of intervention for persons with hearing loss whenever it can be provided without any risks.

## **5.9 Summary**

Bilateral cochlear implantation has taken the leading role worldwide in providing people with bilateral severe-to-profound hearing loss with superior hearing sensitivity. The results obtained with bilateral cochlear implants indicate that BCIs can more closely approximate key aspects of natural hearing than unilateral implants. In short, bilateral cochlear implants as were found in this study provide users with the following objective and subjective outcomes:

- Enhanced hearing sensitivity across the speech frequency range;
- Improved speech understanding and ability to discriminate speech by separating the interfering noise from the target speech signal;
- Improved localization acuity, that is not yet superior for sounds presented binaurally;
- Participation in social activities, including conversations with more than one person and having a conversation on the telephone;
- A feeling of enhanced self-confidence and self-esteem;
- Improved communication and listening that is less demanding and tiring
- Binaural hearing, mainly related to the head shadow effect.

This research contributes to the field of Audiology and will contribute to the worldwide data pool concerning bilateral cochlear implants.

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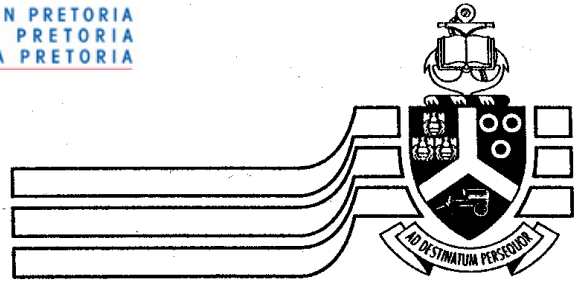
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## **APPENDIX A**

### **Letter of approval from the head of the PCIP**





## University of Pretoria

### Department of Communication Pathology Speech, Voice and Hearing Clinic

Tel: +27 12 420 2815

Fax : +27 12 420 3517

Email : nellie.venter@up.ac.za

June 2007

Prof. J.G. Swart  
Head: E.N.T. Department  
Pretoria Academic Hospital  
Pretoria  
0001

Dear Professor Swart

### **RE: PERMISSION TO CONDUCT A STUDY WITH CLIENTS OF THE PCIP**

I am a part-time student at the University of Pretoria in the Department of Communication Pathology. I enrolled for with the degree M. Communication Pathology in January 2007. As you are aware, the requirements of the mentioned degree entails that the student execute meticulous research and complete a dissertation.

I have chosen the current most dynamic and exciting field of cochlear implantation in which to do research. The aim of my research will be to investigate whether the objective outcomes of bilateral cochlear implantation.

All the adults (>18 years) who received their bilateral implants larger that 6 months ago, within the Pretoria Cochlear Implant Program (PCIP) will be asked to participate in this study. Extensive objective audiometric assessments will be performed to obtain the necessary information to determine the objective

outcomes. The required subjective information will be obtained through questionnaires to the participants, to a significant other person and through a mutual semi-structured interview. It is my sincere belief that the results of this study will enable any cochlear implant team and potential candidates to better understand and exert the outcomes of bilateral implant use. Furthermore the results of this research study will enable the PCIP to make evidence-based recommendations, and potential clients to make informed decisions regarding receipt of a bilateral cochlear implant. This can be based on the triangulation of results that will be obtained in this study, as both objective and subjective outcomes of bilateral cochlear implant users within the PCIP will be investigated.

Thank you in advance.

Kind regards,

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Tania Swart  
Student

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Mrs. PH Venter  
Study leader

---

Prof: B Louw  
Head of Dept. of Communication Pathology

---

Prof J.G. Swart:  
Head of E.N.T. Department

# **APPENDIX B**

## **Back ground questionnaire**



## BACKGROUND QUESTIONNAIRE

### The outcomes of bilateral cochlear implants in adults

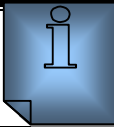
Dear Candidate,

Thank you for your preliminary decision to participate in this study. During our telephonic conversation we agreed to meet at the University of Pretoria, in the foyer of the Department of Communication Pathology on \_\_\_\_\_. For the purpose of this study, it is important that a significant other person will accompany you on the day of the evaluation. The researcher also requests that you complete and bring this questionnaire with. On the day of evaluation you will be asked to sign a letter of informed consent, fill out a questionnaire, participate in an interview, and in audiometric assessments (last mentioned for participant only). The researcher looks forward in meeting you and hope that you are just as excited regarding the 'outcome' of the 'outcomes' under investigation!

DEMOGRAPHIC INFORMATION	ANSWER
1. Gender	_____
2. Marital status	_____
3. Age when severe-to-profound sensorineural hearing loss was first detected.	_____
4. Age / Date when first cochlear implant (CI) was received.	_____
5. Which ear was first implanted?	_____
6. Age / Date when second CI was received.	_____
7. Did you wear a hearing aid (HA) in the contra-lateral (non-implanted ear) after receipt of your first CI?	_____
8. For how long did you use bimodal amplification (CI + HA)?	_____
9. Type of CI devices	R _____ L _____
10. Your current occupation?	_____
11. How long after receipt of your second implant did you return to work?	_____
12. Approximately how many hours do you use both your CIs everyday?	_____
13. Did you have any problems / complications during or after second CI surgery?	_____

Thank you! Please remember to bring this questionnaire with.

Regards, Tania Swart (082 376 5077)



## AGTERGRONDSINLIGTING

### Die uitkomst van bilaterale kogleêre inplantings in volwassenes

Geagte Meneer/Mevrou,

Baie dankie dat u bereid is om deel te neem aan die betrokke studie. Gedurende ons telefoongesprek het ons ooreengekom om op \_\_\_\_\_ by die Universiteit van Pretoria in die voorporataal van die Departement Kommunikasie Patologie te ontmoet. Die navorser verlang dat u 'n belangrike ander persoon sowel as hierdie bondige vraelys voltooi en op die dag van die evaluasie, saambring. Daar sal op die dag van die evaluasie van u verlang word om 'n ingeligte toestemmingsbrief te onderteken, 'n vraelys in te vul, om deel te neem aan 'n onderhoud sowel as oudiologiese toetsing (lg. slegs van toepassing op die persoon met die bilaterale kogleêre inplanting). Die navorser sien uit om u te ontmoet en hoop dat u dieselfde entoesiasme rondom die uitkomst ter ondersoek deel.

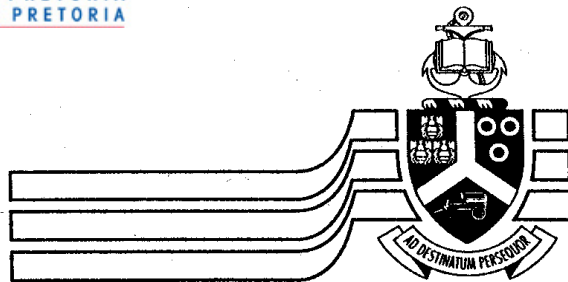
DEMOGRAFIESE INLIGTING	ANTWOORD
1. Geslag	_____
2. Huwelikstatus	_____
3. Ouderdom wanneer ernstig-tot-totale sensories neurale gehoorverlies geïdentifeseer is?	_____
4. Datum / Ouderdom van eerste kogleêre inplanting (KI)?	_____
5. Watter oor was eerste geïmplanteer?	_____
6. Datum / Ouderdom van tweede KI?	_____
7. Het u van bimodale (gehoorapparaat en KI) gebruik gemaak na die eerste KI?	_____
8. Indien wel, vir hoe lank het u van bimodale versterking gebruik gemaak?	_____
9. Wat se tipe KI 'apparate' gebruik u in elke oor onderskeidelik?	R _____ L _____
10. Werk u tans / is u 'n skolier?	_____
11. Indien wel, hoe lank na ontvangs van u tweede kogleêre inplanting kon u terugkeer werk / skool toe?	_____
12. Ongeveer hoeveel uur per dag gebruik u albei KIs?	_____
13. Was daar enige komplikasies tydens of na u tweede KI sjirurgie?	_____

Baie dankie! Onthou asseblief om hierdie vraelys saam te bring.

Groete, Tania Swart (082 376 5077)

# **APPENDIX C**

## **Letter of informed consent**



## University of Pretoria

### Department of Communication Pathology Speech, Voice and Hearing Clinic

Tel: +27 12 420 2815  
Fax : +27 12 420 3517  
Email : nellie.venter@up.ac.za

June 2007

Dear Participant,

#### **RE: LETTER OF INFORMED CONSENT**

*Please read through the following informed consent letter and sign the attached informed consent form, should you approve.*

I hereby agree to participate in the research project at the University of Pretoria. As participant I understand that I will be asked to complete a questionnaire, take part in an interview and participate in audiometric assessments (last mentioned for participants only). I know that there is no right or wrong answer, but that true reflections will add to the validity of this study. I therefore agree to give my full co-operation and complete all tasks with honesty and to the best of my ability. I am also aware that any comment, answer or responses will be kept strictly confidential and that my anonymity will be conserved at all times. I know that participating in this study is completely voluntary and that I have the right to withdraw at any time during the procedures.

\_\_\_\_\_  
Tania Swart

\_\_\_\_\_  
Mrs. PH Venter

\_\_\_\_\_  
Prof. B Louw

**INFORMED CONSENT FORM**

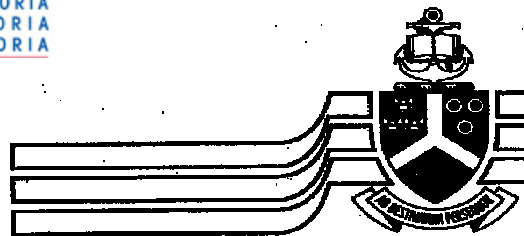
We \_\_\_\_\_ & \_\_\_\_\_ have read all the above information, and willingly agree to participate in this study. This form was completed at the Department of Communication Pathology at the University of Pretoria on \_\_\_\_\_ 2007.

\_\_\_\_\_  
Participant

\_\_\_\_\_  
Significant other person

\_\_\_\_\_  
Tania Swart





## Universiteit van Pretoria

Departement Kommunikasiepatologie  
Sprak- Stem- en Gehoorkliniek  
Tel : +27 12 420 2815  
Faks : +27 12 420 3517  
E-posadres : nellie.venter@up.ac.za

Junie 2007

Geagte Deelnemer,

### **IN SAKE: INGELIGTE TOESTEMMING**

*Lees asb. deur die volgende sake ingevolge ingeligte toestemming en teken onderaan die brief indien u saamstem.*

Hiermee bevestig ek dat ek graag sal deelneem aan die studie by die Universiteit van Pretoria. As deelnemer verstaan ek dat daar van my verwag gaan word om 'n vraelys te voltooi, deel te neem aan 'n onderhoud en deel te neem aan oudiometriese toetse (lg. is slegs op die deelnemer van toepassing). Ek weet dat my antwoorde of response nie as reg of verkeerd beskou sal word nie, maar dat my ware ervarings en refleksie daarvan tot die geldigheid van hierdie studie sal bydra. Ek sal daarom my bes probeer om my volle samewerking te gee, en alle take met eerlikheid na die beste van my vermoë te voltooi. Ek is ook bewus daarvan dat al my aanmerkings, antwoorde en response streng vertroulik hanteer sal word en dat my identiteit ten alle tye anoniem sal bly. Ek dra verder ook kennis dat deelname aan hierdie studie totaal vrywillig is en dat ek die reg het om ten enige tyd te onttrek.

\_\_\_\_\_  
Tania Swart

\_\_\_\_\_  
Mrs. PH Venter

\_\_\_\_\_  
Prof. B Louw

**INGELIGTE TOESTEMMING VORM**

Ons \_\_\_\_\_ & \_\_\_\_\_ het al die bogenoemde inligting noukeurig deurgelees en stel belang om aan die studie deel te neem. Hierdie vorm is op \_\_\_\_\_ 2007, in die Departement van Kommunikasie Patologie by die Universiteit van Pretoria voltooi.

\_\_\_\_\_  
Deelnemer

\_\_\_\_\_  
Belangrike ander persoon

\_\_\_\_\_  
Tania Swart

# **APPENDIX D**

## **Semi-structured interview**



## INTERVIEW SCHEDULE

- *Brief discussion of responses obtained in the background questionnaire*
- *Questions to be discussed in the interview*

1. From the background questionnaire, for persons who have an occupation, what does your work entail? / from the background questionnaire, for persons who are unemployed / at school / retired, with what do you keep yourself busy everyday?

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2. Do you think having a 2<sup>nd</sup> CI affects your work performance / daily living in any way?

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---

3. What were your friends / colleagues reactions when they heard that you were going to get a second cochlear implantation?

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---

---

4. Were you scared of having surgery with your first cochlear implantation?

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---

---

If yes, were you just as scared the second time?

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---

---

5. Who was responsible for the funding of your second cochlear implant?

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6. Did the medical aid help with the funding of the first and second cochlear implant?

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---

---

7. Do you think the outcomes of having a second cochlear implant are worth the financial costs involved?

---

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---



8. Do you think your hearing has much improved since you received your second cochlear implant?

---

---

---

9. What does the term 'quality of life' mean to you?

---

---

---

10. Do you think your quality of life has much improved since you received your second cochlear implant?

---

---

---

11. Would you recommend a second cochlear implant to a unilateral CI user?  
Why?

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12. If you could reconsider, would you still want to have a second cochlear implant?  
Why?

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---

---

13. What was the main reason for your decision to obtain a second cochlear implant?

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- *Instructions for the proposed audiometric testing to be given after completion of the interview.*



## ONDERHOUDSKEDULE

- *Vlugtige bespreking van antwoorde soos weergegee in agtergrondsinsligting vraelys.*
- *Moontlike vrae ter bespreking in die geantisipeerde onderhoud.*

1. Vanuit die agtergrondsinsligting vraelys vir diegene wat werk, wat se tipe werk doen u? / Vanuit die agtergrondsinsligting vraelys vir diegene wat nie tans / meer werk nie, waarmee hou u uself daaglik besig?

---

---

---

2. Dink u dat 'n tweede kogleêre inplanting (KI) u werksprestasie / afhandeling van alledaagse take op enige manier beïnvloed? Indien ja, hoe?

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---

---

3. Wat was u vriende en/of mede-werkers se reaksie toe hulle verneem dat u 'n tweede KI gaan kry?

---

---

---

4. Was u enigsins angstig of bang vir die sjirurgiese prosedure van u eerste KI?

---

---

---

Indien wel, was u net so angstig of bang vir die tweede KI se sjirurgie?

---

---

---

5. Wie was verantwoordelik vir die betaling van die eerste en tweede kogleêre inplanting?

---

---

---

6. Het u mediese fonds enigsins tot die onkoste bygedra?

---

---

---

7. Dink u die uitkomst van twee kogleêre inplantings is die finansiële onkoste werd?

---

---

---



8. Voel u dat u beter kan hoor vandat u 'n tweede kogleêre inplanting gekry het?

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---

---

9. Wat beteken die term kwaliteit van lewe vir u?

---

---

---

10. Voel u dat u kwaliteit van lewe verbeter het vandat u 'n tweede KI ontvang het?

---

---

---

11. Sal u 'n tweede KI vir persone met unilaterale inplantings aanbeveel? Hoekom?

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12. Indien u alles kan heroorweeg, sal u weer dieselfde besluit neem om 'n tweede KI te kry? Hoekom?

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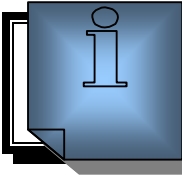
13. Wat was die hoofrede hoekom u besluit het om 'n tweede kogleere inplanting te kry?

- *Die instruksies vir die uitvoer van die oudiometriese toetsing sal na afloop van die onderhoud aan die deelnemer verduidelik word.*

## **APPENDIX E**

### **Questionnaire for the subject with BCIs**





## QUESTIONNAIRE for the subject with BCIs

COMMUNICATION ACTIVITIES: Investigating subjective speech and hearing performance including spatial orientation, quality of sounds and speech perception in quiet and in noise.

***Please indicate your ability by crossing out the appropriate answer for each question.***

1.) Are you able to hear all the sounds in your environment?

Never	Sometimes	Regularly	Usually	Always
-------	-----------	-----------	---------	--------

2.) Are you able to recognize the source of the sounds in your environment?

Never	Sometimes	Regularly	Usually	Always
-------	-----------	-----------	---------	--------

3.) Are you able to localize where a sound is coming from in a quiet setting?

Never	Sometimes	Regularly	Usually	Always
-------	-----------	-----------	---------	--------

4.) Are you able to localize where a sound is coming from in a noisy setting?

Never	Sometimes	Regularly	Usually	Always
-------	-----------	-----------	---------	--------

5.) Are you able to localize where a sound is coming from in an unfamiliar setting?

Never	Sometimes	Regularly	Usually	Always
-------	-----------	-----------	---------	--------

6.) Can you tell from the sound of voice in/to which direction a person is moving (coming toward you/ moving away)?

Never	Sometimes	Regularly	Usually	Always
-------	-----------	-----------	---------	--------

7.) Can you tell from the sound of voice in/to which direction a person is moving (left to right/ right to left)

Never	Sometimes	Regularly	Usually	Always
-------	-----------	-----------	---------	--------

8.) Can you follow what a person says in a conversation in a quiet setting?

Never	Sometimes	Regularly	Usually	Always
-------	-----------	-----------	---------	--------

9.) Can you follow what a person says if a continuous background noise (a fan/ running water) is present?

Never	Sometimes	Regularly	Usually	Always
-------	-----------	-----------	---------	--------

10.) Can you follow a conversation in a group of about five people in quiet?

Never	Sometimes	Regularly	Usually	Always
-------	-----------	-----------	---------	--------

11.) Can you follow a conversation in a group of about five people in a noisy restaurant if you can see everyone?

Never	Sometimes	Regularly	Usually	Always
-------	-----------	-----------	---------	--------

12.) Can you follow a conversation in a group of about five people in a noisy restaurant if you can not see everyone?

Never	Sometimes	Regularly	Usually	Always
-------	-----------	-----------	---------	--------

13.) Can you have a conversation on the telephone?

Never	Sometimes	Regularly	Usually	Always
-------	-----------	-----------	---------	--------

14.) With which ear do you prefer listening on the telephone?

R	L
---	---

15.) If you are listening to someone on the telephone and someone next to you starts talking, can you follow what is being said by both persons?

Never	Sometimes	Regularly	Usually	Always
-------	-----------	-----------	---------	--------

16.) Do you enjoy listening to music?

Yes	No
-----	----

If no, please skip question 17 and 18

17.) Can you determine which instruments are being played if you listen to music?

Never	Sometimes	Regularly	Usually	Always
-------	-----------	-----------	---------	--------

18.) Does it sound clear and natural?

Never	Sometimes	Regularly	Usually	Always
-------	-----------	-----------	---------	--------

19.) Do you speechread?

Yes	No
-----	----

If no, please skip question 20 and 21

20.) What was your ability to speechread with one cochlear implant?

Poor	Fair	Average	Good	Excellent
------	------	---------	------	-----------

21.) What is your ability to speechread with two cochlear implants?

Excellent	Good	Average	Fair	Poor
-----------	------	---------	------	------

22.) Can you easily judge another person's mood by the sound of their voice?

Never	Sometimes	Regularly	Usually	Always
-------	-----------	-----------	---------	--------

23.) Does your own voice sound natural to you?

Never	Sometimes	Regularly	Usually	Always
-------	-----------	-----------	---------	--------

24.) Do everyday sounds that you hear seem to have an artificial or unnatural quality?

Always	Usually	Regularly	Sometimes	Never
--------	---------	-----------	-----------	-------

CONTEXTUAL FACTORS: Investigating subjective environmental factors such as work related issues, financial implications and safety measures.

25.) If any, what are the softest sounds in your environment that you do not hear?

---



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26.) Are there contexts in which you prefer not to use both cochlear implants?

Always	Usually	Regularly	Sometimes	Never
--------	---------	-----------	-----------	-------

27.) Are there contexts in which you prefer using both?

Never	Sometimes	Regularly	Usually	Always
-------	-----------	-----------	---------	--------

28.) Do you feel safer since your second cochlear implant (e.g. walking alone over the street with hectic traffic)?

Never	Sometimes	Regularly	Usually	Always
-------	-----------	-----------	---------	--------

29.) If you are outside, can you predict how far away a bus is only by listening to the sound of the bus?

Never	Sometimes	Regularly	Usually	Always
-------	-----------	-----------	---------	--------

30.) If you are outside, can you predict by the sound of footsteps whether the person is coming towards you or going away?

Never	Sometimes	Regularly	Usually	Always
-------	-----------	-----------	---------	--------

31.) How satisfied are you with completion of your daily tasks since receipt of your second cochlear implant?

Not satisfied	Fairly satisfied	No difference	Satisfied	Very satisfied
---------------	------------------	---------------	-----------	----------------

32.) Do you think having two cochlear devices affects your work/daily tasks performance?

No change	Some change	Fair change	Few changes	Many changes
-----------	-------------	-------------	-------------	--------------

33.) If you are employed, how does your present income compare to your income prior to the second cochlear implant?

Decreased	Decreased slightly	No change	Increased slightly	Increased
-----------	--------------------	-----------	--------------------	-----------

34. Are you an advocate for your hearing impairment? For example, if you do not understand what a person had said, would you ask for clarification by saying: "I have a hearing impairment can you please speak louder/more clearly?"

Never	Sometimes	Regularly	Usually	Always
-------	-----------	-----------	---------	--------

35.) How often does the above (in nr. 34) occur?

Never	Sometimes	Regularly	Usually	Always
-------	-----------	-----------	---------	--------

PSYCHOSOCIAL ISSUES: Investigating subjective social participation and feelings amongst friends, family and colleagues at work.

36.) Whose decision was it to apply for a second cochlear implant?

My own	Significant other's	Audiologist	Mutual decision	Can't remember
--------	---------------------	-------------	-----------------	----------------

37.) What was your family's reaction to the decision to attain a second cochlear implant?

Negative	Slightly negative	Neutral	Positive	Very positive
----------	-------------------	---------	----------	---------------

38.) Do you think your significant other person can notice a difference in your hearing since receipt of a second cochlear implant?

Never	Sometimes	Regularly	Usually	Always
-------	-----------	-----------	---------	--------

39.) Do you think your significant other person can notice a difference in your quality of life since receipt of a second cochlear implant?

Never	Sometimes	Regularly	Usually	Always
-------	-----------	-----------	---------	--------

40.) How would you rate the quality of your relationship with your co-workers/friends after your first CI?

Poor	Fair	Average	Good	Excellent
------	------	---------	------	-----------

41.) How would you rate the quality of your relationship with your coworkers/friends after your second CI?

Poor	Fair	Average	Good	Excellent
------	------	---------	------	-----------

42.) Which aspects changed since your receipt of a second cochlear implant?

(Please tick all that apply)

Hearing abilities	Improved self-esteem & confidence	Better speech perception in noise	Less anxiety & frustration	No change noticed
-------------------	-----------------------------------	-----------------------------------	----------------------------	-------------------

43.) Do you enjoy social events?

Never	Sometimes	Regularly	Usually	Always
-------	-----------	-----------	---------	--------

44.) Does your hearing impairment play a leading role in your answer in question nr. 43?

Always	Usually	Regularly	Sometimes	Never
--------	---------	-----------	-----------	-------

45.) Does it bother you that you are still considered to be 'hearing impaired'?

Always	Usually	Regularly	Sometimes	Never
--------	---------	-----------	-----------	-------

46.) Are there situations in which you would feel happier if you were not hearing impaired?

Always	Usually	Regularly	Sometimes	Never
--------	---------	-----------	-----------	-------

47.) Are there places you avoid going to because of your hearing problem?  
Please elaborate.

---



---

48.) Does the cosmetic appearance of two CI devices bother you?

Always	Usually	Regularly	Sometimes	Never
--------	---------	-----------	-----------	-------

49.) In general to what extent has bilateral cochlear implantation altered your life?  
Please elaborate.

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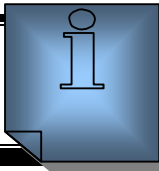


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Thank you for participating!



## VRAELYS

### vir die deelnemer met BKIs

**KOMMUNIKASIE AKTIWITEITE:** Die ondersoek van subjektiewe spraak en gehoor uitkomst insluitende ruimtelike oriëntasie, kwaliteit van klanke en spraakpersepsie in stilte en in geraas.

***Dui asseblief u antwoord aan deur 'n kruisie oor die toepaslike antwoord te trek.***

1. Is u in staat om alle klanke in u onmiddellike omgewing te hoor?

Nooit	Soms	Gereeld	Gewoonlik	Altyd
-------	------	---------	-----------	-------

2. Is u in staat om die bron van die klanke in u omgewing te herken?

Nooit	Soms	Gereeld	Gewoonlik	Altyd
-------	------	---------	-----------	-------

3. Is u in staat om 'n klank in 'n stil omgewing te lokaliseer?

Nooit	Soms	Gereeld	Gewoonlik	Altyd
-------	------	---------	-----------	-------

4. Is u in staat om 'n klank in 'n raserige omgewing te lokaliseer?

Nooit	Soms	Gereeld	Gewoonlik	Altyd
-------	------	---------	-----------	-------

5. Is u in staat om 'n klank in 'n onbekende omgewing te lokaliseer?

Nooit	Soms	Gereeld	Gewoonlik	Altyd
-------	------	---------	-----------	-------

6. Kan u deur middel van 'n persoon se stem die rigting waarna hy beweeg bepaal (beweeg nader aan u / verder weg van u)?

Nooit	Soms	Gereeld	Gewoonlik	Altyd
-------	------	---------	-----------	-------

7. Kan u deur middel van 'n persoon se stem die rigting waarin hy beweeg bepaal (links na regs / regs na links)?

Nooit	Soms	Gereeld	Gewoonlik	Altyd
-------	------	---------	-----------	-------

8. Is u in staat om 'n persoon se gesprek in 'n 'stil omgewing', te volg?

Nooit	Soms	Gereeld	Gewoonlik	Altyd
-------	------	---------	-----------	-------

9. Is u in staat om 'n persoon se gesprek met voortdurende agtergrondsgeraas te volg ('n waaier / vloeiende water)?

Nooit	Soms	Gereeld	Gewoonlik	Altyd
-------	------	---------	-----------	-------

10. Is u in staat om 'n groeps gesprek van ongeveer vyf mense in 'n 'stil omgewing' te volg?

Nooit	Soms	Gereeld	Gewoonlik	Altyd
-------	------	---------	-----------	-------

11. Is u in staat om 'n groeps gesprek van ongeveer vyf mense in 'n raserige restaurant, waar u almal in die gesprek kan sien, te volg?

Nooit	Soms	Gereeld	Gewoonlik	Altyd
-------	------	---------	-----------	-------

12. Is u in staat om 'n groeps gesprek van ongeveer vyf mense in 'n raserige restaurant, waar u nie almal in die gesprek kan sien nie, te volg?

Nooit	Soms	Gereeld	Gewoonlik	Altyd
-------	------	---------	-----------	-------

13. Is u in staat om 'n gesprek oor die telefoon te voer?

Nooit	Soms	Gereeld	Gewoonlik	Altyd
-------	------	---------	-----------	-------

14. Met watter oor verkies u om oor die telefoon te luister?

R	L
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15. Tydens 'n telefoongesprek begin 'n ander persoon langs u te praat, is u in staat om te volg wat deur beide persone gesê word?

Nooit	Soms	Gereeld	Gewoonlik	Altyd
-------	------	---------	-----------	-------

16. Geniet u dit om na musiek te luister?

Ja	Nee
----	-----

Indien nee, slaan asb. vraag 17 en 18 oor.

17. Wanneer u na musiek luister, is u in staat om al die instrumente te identifiseer?

Nooit	Soms	Gereeld	Gewoonlik	Altyd
-------	------	---------	-----------	-------

18. Is die klank suiwer en natuurlik?

Nooit	Soms	Gereeld	Gewoonlik	Altyd
-------	------	---------	-----------	-------

19. Spraaklees u?

Ja	Nee
----	-----

Indien nee, slaan asb. vraag 20 en 21 oor.

20. Wat was u vermoë om met een kogleêre inplanting te spraaklees?

Uitstekend	Goed	Gemiddeld	Redelik swak	Swak
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21. Wat is u vermoë om met twee kogleêre inplantings te spraaklees?

Swak	Redelik swak	Gemiddeld	Goed	Uitstekend
------	--------------	-----------	------	------------

22. Is u in staat om 'n persoon se gemoedstoestand deur middel van sy stem te bepaal?

Nooit	Soms	Gereeld	Gewoonlik	Altyd
-------	------	---------	-----------	-------

23. Klink u eie stem vir u natuurlik?

Nooit	Soms	Gereeld	Gewoonlik	Altyd
-------	------	---------	-----------	-------

24. Klink alledaagse klanke se kwaliteit onnatuurlik?

Altyd	Gewoonlik	Gereeld	Soms	Nooit
-------	-----------	---------	------	-------

**KONTEKSTUELE FAKTORE:** Die ondersoek van subjektiewe omgewingsfaktore soos werksverwante sake, finansiële implikasies en veiligheidsmaatreëls.

25. Indien enige, wat is die sagste klanke in u omgewing wat u nie kan hoor nie?

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26. Is daar kontekste waarin u verkies om nie albei kogleêre inplantings te dra nie?

Nooit	Soms	Gereeld	Gewoonlik	Altyd
-------	------	---------	-----------	-------

27. Is daar kontekste waarin u verkies om wel albei kogleêre inplantings te dra?

Nooit	Soms	Gereeld	Gewoonlik	Altyd
-------	------	---------	-----------	-------

28. Voel u veiliger vandat u twee kogleêre inplantings dra (bv. Om alleen oor 'n straat in besige verkeer te stap)?

Nooit	Soms	Gereeld	Gewoonlik	Altyd
-------	------	---------	-----------	-------

29. Is u in staat om te voorspel hoe ver 'n bus weg is deur slegs na die geluid van die bus te luister?

Nooit	Soms	Gereeld	Gewoonlik	Altyd
-------	------	---------	-----------	-------

30. Is u in staat om te voorspel of 'n persoon na u toe aangestap kom, of weg van u beweeg deur slegs na die persoon se voetspore te luister?

Nooit	Soms	Gereeld	Gewoonlik	Altyd
-------	------	---------	-----------	-------

31. Hoe tevrede is u met die afhandeling van u daaglikse take vandat u 'n tweede kogleêre inplanting ontvang het?

Nie tevrede	Redelik tevrede	Geen verskil	Tevrede	Baie tevrede
-------------	-----------------	--------------	---------	--------------

32. Dink u dat die gebruik van twee kogleêre inplantings 'n verskil in u werk of daaglikse take teweeg bring?

Geen veranderings	Sommige veranderings	Weinige veranderings	Min veranderings	Baie veranderings
-------------------	----------------------	----------------------	------------------	-------------------

33. Indien u werk, hoe vergelyk u huidige inkomste met u inkomste voordat u 'n tweede kogleêre inplanting ontvang het?

Verminder	Effens verminder	Geen verandering	Effens toeneem	Toegeneem
-----------	------------------	------------------	----------------	-----------



34. Is u selfgeldend ten opsigte van u gehoorverlies? Byvoorbeeld, wanneer u nie begryp wat 'n persoon gesê het nie sal u vir verduideliking vra deur te sê: "Ek het 'n gehoorverlies, praat asseblief effens harder of duideliker sodat ek ook die gesprek kan volg?"

Nooit	Soms	Gereeld	Gewoonlik	Altyd
-------	------	---------	-----------	-------

35. Hoe gereeld gebeur voorvalle soos in vraag 34 beskryf?

Nooit	Soms	Gereeld	Gewoonlik	Altyd
-------	------	---------	-----------	-------

PSIGOSOSIALE SAKE: Die ondersoek van subjektiewe sosiale deelname en gevoelens onder vriende, familie, en kollegas by die werk.

36. Wie se besluit was dit om vir 'n tweede kogleêre inplanting aansoek te doen?

My eie	Belangrike ander persoon	Oudioloog	Gemeenskaplike besluit	Kan nie onthou nie
--------	--------------------------	-----------	------------------------	--------------------

Wat was u familie se reaksie op die besluit om 'n tweede kogleêre inplanting te kry?

Negatief	Effens negatief	Neutraal	Positief	Baie positief
----------	-----------------	----------	----------	---------------

38. Dink u dat u belangrike ander persoon 'n verskil in u gehoorvermoë kan agterkom sedert die aanskakeling van die tweede kogleêre inplanting?

Nooit	Soms	Gereeld	Gewoonlik	Altyd
-------	------	---------	-----------	-------

39. Dink u dat u belangrike ander persoon 'n verskil in u kwaliteit van lewe kan agterkom sedert die aanskakeling van die tweede kogleêre inplanting?

Nooit	Soms	Gereeld	Gewoonlik	Altyd
-------	------	---------	-----------	-------

40. Wat was die kwaliteit van u verhouding met mede-werkers/vriende met een kogleêre inplanting?

Swak	Redelik swak	Gemiddeld	Goed	Uitstekend
------	--------------	-----------	------	------------

41. Wat is die kwaliteit van u verhouding met mede-werkers/vriende met twee kogleêre inplantings?

Swak	Redelik swak	Gemiddeld	Goed	Uitstekend
------	--------------	-----------	------	------------

42. Watter aspekte het verander vandat u twee kogleêre inplantings gebruik?

**merk asb. almal wat van toepassing is**

Gehoervermoë	Verbeterde selfbeeld en self vertrou	Verbeterde spraakpersepsie in geraas	Minder angs en frustrasie	Geen verandering agtergekom
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43. Geniet u sosiale aktiwiteite?

Nooit	Soms	Gereeld	Gewoonlik	Altyd
-------	------	---------	-----------	-------

44. Speel u gehoorverlies 'n bepalende faktor in u antwoord in vraag 43?

Altyd	Gewoonlik	Gereeld	Soms	Nooit
-------	-----------	---------	------	-------

45. Pla dit u dat u nogsteeds beskou word as 'n 'persoon met 'n gehoorverlies'?

Altyd	Gewoonlik	Gereeld	Soms	Nooit
-------	-----------	---------	------	-------

46. Is daar situasies waarin u meer gelukkig sou wees indien u nie 'n gehoorverlies gehad het nie?

Altyd	Gewoonlik	Gereeld	Soms	Nooit
-------	-----------	---------	------	-------

47. Is daar kontekste wat u vermy om heen te gaan a.g.v. u gehoorverlies? Brei asb.uit.

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48. Pla die kosmetiese voorkoms van twee kogleêre inplantings u?

Altyd	Gewoonlik	Gereeld	Soms	Nooit
-------	-----------	---------	------	-------

49. Hoe het bilaterale kogleêre inplantings u lewe oor die algemeen verander? Brei asb. uit.

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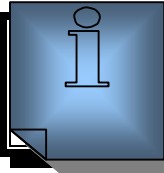


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Baie dankie vir u deelname!

## **APPENDIX F**

### **Questionnaire for the significant other person**



# QUESTIONNAIRE

## for the significant other person...

CONTEXTUAL FACTORS: Investigating subjective environmental factors such as work related issues, financial implications and safety measures.

**Please indicate your perception of the subject with BCIs' ability by crossing out the appropriate answer for each question.**

1. If any, what are the softest sounds in her/his environment that she/he does not hear?

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2. Are there contexts in which she/he prefers not to use both cochlear implants?

Always	Usually	Regularly	Sometimes	Never
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3. Are there contexts in which she/he prefers using both?

Never	Sometimes	Regularly	Usually	Always
-------	-----------	-----------	---------	--------

4. Does she/he feel safer since she/he received a second cochlear implant (e.g. walking alone over the street with hectic traffic)?

Never	Sometimes	Regularly	Usually	Always
-------	-----------	-----------	---------	--------

5. If she/he is outside, can she/he predict how far away a bus is only by listening to the sound of the bus?

Never	Sometimes	Regularly	Usually	Always
-------	-----------	-----------	---------	--------

6. If she/he is outside, can she/he predict by the sound of footsteps whether the person is coming towards her/him or going away?

Never	Sometimes	Regularly	Usually	Always
-------	-----------	-----------	---------	--------

7. How satisfied is she/he with completion of her/his daily tasks since receipt of her/his second cochlear implant?

Not satisfied	Fairly satisfied	No difference	Satisfied	Very satisfied
---------------	------------------	---------------	-----------	----------------

8. Do you think having two cochlear devices affects her/his work/daily tasks performance?

No change	Some change	Fair change	Few changes	Many changes
-----------	-------------	-------------	-------------	--------------

9. If she/he is employed, how does her/his present income compare to her/his income prior to the second cochlear implant?

Decreased	Decreased slightly	No change	Increased slightly	Increased
-----------	--------------------	-----------	--------------------	-----------

10. Is she/he an advocate for her/his hearing impairment by example asking for clarification if she/he did not understand what a person said (e.g. "I have a hearing impairment can you please speak louder/more clearly")?

Never	Sometimes	Regularly	Usually	Always
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11. How often does the above (in nr 10.) occur?

Never	Sometimes	Regularly	Usually	Always
-------	-----------	-----------	---------	--------

PSYCHOSOCIAL ISSUES: Investigating subjective social participation and feelings amongst friends, family and colleagues at work.

12. Whose decision was it to apply for a second cochlear implant?

Recipient's	My own	Audiologist's	Mutual decision	Can't remember
-------------	--------	---------------	-----------------	----------------

13. What was your family's reaction to the decision to attain a second cochlear implant?

Negative	Slightly negative	Neutral	Positive	Very positive
----------	-------------------	---------	----------	---------------

14. Can you notice a difference in her/his hearing since receipt of a second cochlear implant?

Never	Sometimes	Regularly	Usually	Always
-------	-----------	-----------	---------	--------

15. Can you notice a difference in her/his quality of life since receipt of a second cochlear implant?

Never	Sometimes	Regularly	Usually	Always
-------	-----------	-----------	---------	--------

16. How would you rate the quality of her/his relationship with her/his co-workers/friends after her/his first CI?

Poor	Fair	Average	Good	Excellent
------	------	---------	------	-----------

17. How would you rate the quality of her/his relationship with her/his co-workers/friends after her/his second CI?

Poor	Fair	Average	Good	Excellent
------	------	---------	------	-----------

18. What do you think changed since receipt of her/his second cochlear implant?

**Please tick all that apply**

Hearing abilities	Improved self-esteem & confidence	Better speech perception in noise	Less anxiety & frustration	No change noticed
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19. Does she/he enjoy social events?

Never	Sometimes	Regularly	Usually	Always
-------	-----------	-----------	---------	--------

20. Does her/his hearing impairment play a leading role in your answer in question nr.19

Always	Usually	Regularly	Sometimes	Never
--------	---------	-----------	-----------	-------

21. Do you think it bothers her/him that she/he is still considered to be 'hearing impaired'?

Always	Usually	Regularly	Sometimes	Never
--------	---------	-----------	-----------	-------

22. Are there situations in which she/he would feel happier if she/he were not hearing impaired?

Always	Usually	Regularly	Sometimes	Never
--------	---------	-----------	-----------	-------

23. Are there places she/he avoids going to because of her/his hearing problem?  
Please elaborate.

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24. Does the cosmetic appearance of two CI devices bother you?

Always	Usually	Regularly	Sometimes	Never
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25. Do you think the cosmetic appearance of two CI devices bother her/him?

Always	Usually	Regularly	Sometimes	Never
--------	---------	-----------	-----------	-------

26. In general to what extent has bilateral cochlear implantation altered her/his life?  
Please elaborate

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Thank you for participating!



## VRAELYS

### vir die belangrike ander persoon...

KONTEKSTUELE FAKTORE: Die ondersoek van subjektiewe omgewingsfaktore soos werksverwante sake, finansiële implikasies en veiligheidsmaatreëls.

***Dui asseblief u antwoord aan deur 'n kruisie oor die toepaslike antwoord te trek.***

1. Indien enige, wat is die sagste klanke in haar/sy omgewing wat sy/hy nie kan hoor nie?

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2. Is daar kontekste waarin sy/hy verkies om nie albei kogleêre inplantings te dra nie?

Nooit	Soms	Gereeld	Gewoonlik	Altyd
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3. Is daar kontekste waarin sy/hy verkies om wel albei kogleêre inplantings te dra?

Nooit	Soms	Gereeld	Gewoonlik	Altyd
-------	------	---------	-----------	-------

4. Voel sy/hy oor die algemeen veiliger vandat sy/hy twee kogleêre inplantings dra (bv. om alleen oor 'n straat in besige verkeer te stap)?

Nooit	Soms	Gereeld	Gewoonlik	Altyd
-------	------	---------	-----------	-------

5. Is sy/hy in staat om te voorspel hoe ver 'n bus weg is deur slegs na die geluid van die bus te luister?

Nooit	Soms	Gereeld	Gewoonlik	Altyd
-------	------	---------	-----------	-------

6. Is sy/hy in staat om te voorspel of 'n persoon na haar/hom toe aangestap kom, of weg van haar/hom beweeg deur slegs na die persoon se voetstap te luister?

Nooit	Soms	Gereeld	Gewoonlik	Altyd
-------	------	---------	-----------	-------

7. Hoe tevrede is sy/hy met die afhandeling van haar/sy daaglikse take vandat sy/hy 'n tweede kogleêre inplanting ontvang het?

Nie tevrede	Redelik tevrede	Geen verskil	Tevrede	Baie tevrede
-------------	-----------------	--------------	---------	--------------

8. Dink u dat die gebruik van twee kogleêre inplantings 'n verskil in haar/sy werk of daaglikse take teweeg bring?

Geen veranderings	Sommige veranderings	Weinige veranderings	Min veranderings	Baie veranderings
-------------------	----------------------	----------------------	------------------	-------------------

9. Indien sy/hy werk, hoe vergelyk haar/sy huidige inkomste met haar/sy inkomste voordat sy/hy 'n tweede kogleêre inplanting ontvang het?

Verminder	Effens verminder	Geen verandering	Effens toeneem	Toegeneem
-----------	------------------	------------------	----------------	-----------

10. Is sy/hy selfgeldend ten opsigte van haar/sy gehoorverlies? Byvoorbeeld, wanneer sy/hy nie begryp wat 'n persoon gesê het nie, sal sy /hy vir verduideliking vra deur te sê: "Ek het 'n gehoorverlies, praat asb. effens harder of duideliker sodat ek ook die gesprek kan volg?"

Gooit	Soms	Gereeld	Gewoonlik	Altyd
-------	------	---------	-----------	-------

11. Hoe gereeld gebeur voorvalle soos in vraag 10 beskryf?

Nooit	Soms	Gereeld	Gewoonlik	Altyd
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PSIGOSOSIALE SAKE: Die ondersoek van subjektiewe sosiale deelname en gevoelens van vriende, familie, en kollegas by die werk.

12. Wie se besluit was dit om vir 'n tweede kogleêre inplanting aansoek te doen?

My eie	KI* gebruiker Self	Oudioloog	Gemeenskaplike besluit	Kan nie onthou nie
--------	--------------------	-----------	------------------------	--------------------

\* KI: kogleere inplanting

13. Wat was die familie se reaksie op die besluit om 'n tweede kogleêre inplanting te kry?

Negatief	Effens negatief	Neutraal	Positief	Baie positief
----------	-----------------	----------	----------	---------------

14. Kan u sedert die aanskakeling van die tweede kogleêre inplanting, 'n verskil in haar/sy gehoorvermoë agterkom?

Nooit	Soms	Gereeld	Gewoonlik	Altyd
-------	------	---------	-----------	-------

15. Kan u sedert die aanskakeling van die tweede kogleêre inplanting 'n verskil in haar/sy kwaliteit van lewe agterkom?

Nooit	Soms	Gereeld	Gewoonlik	Altyd
-------	------	---------	-----------	-------

16. Wat was die kwaliteit van haar/sy verhouding met mede-werkers/vriende toe sy/hy een kogleêre inplanting gehad het?

Swak	Redelik swak	Gemiddeld	Goed	Uitstekend
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17. Wat is die kwaliteit van haar/sy verhouding met mede-werkers/vriende met twee kogleêre inplantings?

Swak	Redelik swak	Gemiddeld	Goed	Uitstekend
------	--------------	-----------	------	------------



18. Watter aspekte het verander vandat sy/hy twee kogleêre inplantings gebruik?

***Merk asb. almal wat van toepassing is***

Gehoervermoë	Verbeterde selfbeeld en selfvertroue	Verbeterde spraakpersepsie in geraas	Minder angs en frustrasie	Geen verandering agtergekom nie
--------------	--------------------------------------	--------------------------------------	---------------------------	---------------------------------

19. Geniet sy/hy sosiale aktiwiteite?

Nooit	Soms	Gereeld	Gewoonlik	Altyd
-------	------	---------	-----------	-------

20. Speel haar/sy gehoorverlies 'n bepalende faktor in u antwoord in vraag 19?

Altyd	Gewoonlik	Gereeld	Soms	Nooit
-------	-----------	---------	------	-------

21. Pla dit haar/hom dat sy/hy nogsteeds beskou word as 'n 'persoon met 'n gehoorverlies'?

Altyd	Gewoonlik	Gereeld	Soms	Nooit
-------	-----------	---------	------	-------

22. Is daar situasies waarin sy/hy meer gelukkig sou wees indien sy/hy nie 'n gehoorverlies gehad het nie?

Altyd	Gewoonlik	Gereeld	Soms	Nooit
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23. Is daar kontekste wat sy/hy vermy om heen te gaan a.g.v haar/sy gehoorverlies? Brei asb. uit.

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24. Pla die kosmetiese voorkoms van twee kogleêre inplantings u?

Altyd	Gewoonlik	Gereeld	Soms	Nooit
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25. Pla die kosmetiese voorkoms van twee kogleêre inplantings haar/hom?

Altyd	Gewoonlik	Gereeld	Soms	Nooit
-------	-----------	---------	------	-------

26. Hoe het bilaterale kogleêre inplantings sy/haar leefstyl oor die algemeen verander? Brei asb. uit.

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Baie dankie vir u deelname!

## **APPENDIX G**

### **Interpretation of the localization test**

Interpretation of the localization test

<b>FACE FORWARD</b>	<b>PERCEIVED SOUND FROM: R / L / B</b>	<b>ACCURACY</b> √ / X
Present right		
Present left		
Present binaural (L/R)		
<b>FACE BACK</b>		
Present right		
Present left		
Present binaural (L/R)		

R=Right, L=Left, B=Binaural (from both sides simultaneously)

**Face forward:**



**Face back:**



# **APPENDIX H**

## **Ethical clearance**