

**THE CLINICAL UTILITY OF THE VIVOSONIC INTEGRITY  
AUDITORY BRAINSTEM RESPONSE SYSTEM IN  
CHILDREN WITH CEREBRAL PALSY**

by

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## **Abstract**

Determining auditory functioning in difficult-to-test populations such as cerebral palsy (CP) remains a challenge in paediatric audiology. The auditory brainstem response (ABR) is favoured as the procedure to assess auditory functioning in difficult-to-test populations such as CP. The CP population, however, offers unique challenges for the ABR procedure due to the presence of involuntary muscular movements that may compromise the signal-to-noise ratio (SNR) of the ABR. Conventional ABR technology attempts to improve the SNR by the modification of acquisition parameters e.g. adjusting the low cut filter or implementing stricter artifact rejection criteria. However, such modifications may compromise the waveform morphology of the ABR. Furthermore, sedation or general anesthesia can also be used to improve the SNR by reducing excessive muscular movements. The CP population, however, displays a high risk for developing upper airway obstruction when being sedated or anesthetized. Thus, the feasibility and reliability of the conventional ABR may be compromised when being employed in the CP population. In recent years a novel ABR system, the Vivosonic Integrity (VS) ABR has become clinically available. The device incorporates features such as pre-amplification of the ABR signal, Kalman filtering and wireless recording. These features promise to address the limitations of conventional ABR technology to obtain a reliable recording in the midst of excessive myogenic artifact. The aim of this study was therefore to evaluate the clinical utility of the VS system when assessing a sample of children with CP without the use of sedation. The clinical utility of the VS ABR system was determined by comparing its success rates, the threshold correspondence to behavioural pure tone (PT) thresholds and recording time to a conventional ABR system when using click and 0.5 kHz TB stimuli.

A cross-sectional within-subject comparison research design was selected in order to compare thresholds obtained with different procedures. The experimental part of this study was represented by the within-subject control



condition where the VS ABR system and the conventional ABR system were simultaneously conducted in each subject. This unique setup was important in the research as equivalent test conditions in terms of EEG and environmental conditions had to be ensured for both ABR systems. 15 CP subjects between the ages of 12 and 18 years were included in the project. A diagnostic audiological test battery including immittance, distortion product otoacoustic emissions and behavioural audiometry was conducted on each subject prior the administration of the ABR procedures. The variability of the audiological test battery results – between the subjects and when compared to previous research – emphasized the heterogeneity of the CP population. Furthermore, more than half of the research sample (53%; n=15) responded inconsistently to behavioural pure tone (PT) stimuli. It was suggested that the severity of physical impairments as well as additional impairments such as mental retardation might have influenced the consistency of the subjects' responses during behavioural PT audiometry. The ABR results indicated that there were no significant differences with regards to threshold correspondence and recording time between the two ABR systems when using click and 0.5 kHz TB stimuli ( $p>0.05$ ). With regards to the success rates, the VS system was successful in more cases than the conventional ABR system using click and 0.5 kHz TB stimuli. Although results also showed no statistically significant value for click ( $p=.1121$ ) and 0.5 kHz TB stimuli ( $p=.1648$ ), there was a tendency towards the 95% confidence level in both cases suggesting that the VS ABR system may produce a statistically significant success rate for click as well as for 0.5 kHz TB stimuli, provided a larger sample is tested. The research indicated that, since the VS ABR system was more successful across a wider range of subjects during click-evoked and 0.5 kHz TB recordings, it may increase the clinical usefulness of the ABR especially in terms of hearing screening in the CP population. The research suggested that excessive muscular movements during the recordings influenced not only the VS ABR's, but also the conventional ABR's threshold correspondences to PT thresholds as well as the recording time of the measurements. Therefore it may

still be necessary to use a light sedative in some CP patients to reduce excessive myogenic interference despite the possible advantages of the VS ABR system.

**Key words:** Difficult-to-test, cerebral palsy, objective audiometry, auditory brainstem response, signal-noise-ratio, feasibility, threshold correspondence, recording time, Vivosonic Integrity ABR system, conventional ABR system



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## Chapter 1

# INTRODUCTION AND ORIENTATION

*The aim of this chapter is to introduce the research question, to provide the rationale for the study, to explain the terminology used, and to present an overview of the content and the organization of the study.*

### 1.1 Introduction

*'A disabled child has the right to enjoy a full and decent life, in conditions which ensure dignity, promote self-reliance, and facilitate the child's active participation in the community'* (UN Convention on the Rights of the Child, 1989). This statement endorses the right of each disabled child to embrace his/her life to the fullest, implying that disabilities need to be identified and addressed appropriately.

A disability is defined as *'a physical or mental condition that limits a person's movements, senses or activities'* (South African Concise Oxford Dictionary, 2002). Cerebral palsy (CP) is viewed mainly as a physical disability which affects an individual's movements, senses and activities of daily living to varying degrees depending on the type and severity of the condition (Armstrong, 2007; Beckung & Hagberg, 2002; Hutton & Pharoah, 2002). These disabling conditions have far reaching implications not only for the CP child, but also for his/her family and the immediate community as self-reliance and active participation in the community is reduced to a significant degree.

The term *cerebral palsy* refers to a group of disorders of the central nervous system that result in abnormal control of movement or posture (Lawson & Badawi, 2003; Stanton, 1992). These disorders are the result of a lesion(s) before birth (prenatally), during birth (perinatally) or after birth (postnatally), prior to the developing brain reaching maturation (Mechem, 2002). Although the

lesion to the brain is irreversible, CP is regarded as a non-progressive disorder as the neuromuscular symptoms do not usually degenerate over a period of time (Andersen, Irgens, Haagaas, Skranes, Meberg & Vik, 2008; Beckung & Hagberg, 2002; Hutton & Pharoah, 2002; Mechem, 2002; Stanton, 1992).

A variety of neuromuscular symptoms can occur within the population with CP and a classification system was proposed by Minear (1956) in order to elucidate these symptoms. According to this classification, the diverse symptoms are described in terms of the *place* of disability (e.g. quadriplegia); the *type* of disability (e.g. spasticity) and the *severity* of the disability (e.g. mild) (Mechem, 2002; Minear, 1956). Recent literature simplifies this classification to a certain extent and suggests that CP can be classified according to a description of the motor characteristics and the limb involvement on the one hand, and the place of lesion i.e. in pyramidal and extrapyramidal nerve pathways on the other (Wilson-Jones, Morgan & Shelton, 2007). As CP is a diverse medical condition the utilization of a classification system provides a platform of knowledge from where medical personnel including therapists such as occupational therapists and speech therapists can commence intervention in order to address not only the motor disabilities of the condition, but other accompanying disabilities as well.

Although CP is mainly a motor impairment, the condition is often accompanied by associated musculoskeletal problems that are secondary to the brain lesion (O'Shea, 2008; Beckung & Hagberg, 2002; Mechem, 2002). These impairments include dysphagia, speech and language difficulties, auditory dysfunction, vision and cognitive impairments, perceptual and behavioural problems as well as epilepsy (O'Shea, 2008; Workinger, 2005; Mechem, 2002; Stanton, 1992). Recent Norwegian data illustrated that only 28% of children with CP did not display any associated impairments (Andersen et al., 2008), emphasizing the importance of a holistic approach in the treatment of a child with CP. The fact that the related impairments may vary in degree and nature over a period of time (e.g. progressive degeneration is possible), stresses the importance of considering and assessing each associated impairment to ensure appropriate

early intervention services (Kennes, Rosenbaum, Walter, Russel, Raina, Bartlett & Galuppi, 2002; Workinger, 2005).

Associated sensory impairments, in particular hearing loss, occur with relative high incidence in the CP population (Mechem, 2002; Northern & Downs, 2002; Zafeiriou, Andreou & Karasavidou, 2000). Although there are discrepancies regarding the exact incidence of additional hearing loss in this population, data suggest that auditory disorders may occur in 1% to 25% of this population (Fawke, 2007; Kolker, 2004).

Auditory dysfunction disorders refer to pathology in any part of the auditory system. This would include a conductive hearing loss due to middle ear pathology, a sensory hearing loss due to cochlear damage, a NVIII hearing loss due to a lesion of the auditory nerve or to auditory neuropathy/dys-synchrony, or auditory processing problems (Romero, Mendez, Tello & Torner, 2008; Ngo, Tan, Balakrishnan, Lim & Lazaroo, 2006; Sano, Kaga, Kitazumi & Kodama, 2005; Kolker, 2004; Mechem, 2002; Sheykhholeslami & Kaga, 2000; Stanton, 1992). It is important for the audiologist to identify each type of auditory disorder as soon as possible since undetected hearing loss can have detrimental effects on the communication development of a child, especially in terms of language and speech acquisition (Yoshinaga-Itano, 1998).

## **1.2 Background**

A hearing loss is a sensory disability that, if not identified timeously and intervened appropriately, can negatively influence speech and language development and, ultimately, may prevent the child from leading a full and integrated life (Sininger, Doyle & Moore, 1999; Yoshinaga-Itano, 1998). Jamieson (1994:596) stated that *'the essence of a hearing loss is its effect on communication and the resulting impact on cognitive, speech, language and psychosocial development and functioning'*. If a hearing loss, in isolation, can have such an impact on the developing child, it is expected that the combined

effect of a hearing loss in combination with another disabling condition such as CP could be significantly more detrimental to development.

The CP population is generally considered as 'multi-handicapped', since the condition is often characterized by the presence of more than one disability (Workinger, 2005; Mecher, 2002). Considering the fact that CP in itself is an established risk factor for a communication delay, the presence and/or neglect of an additional hearing loss could disable the child's development to an even greater extent (Rossetti, 1996). Hence, the early detection and intervention of a hearing loss in the multi-handicapped population is of the utmost importance, not only to minimize the adverse effects of the sensory deficit (the hearing loss), but also of the overall handicap (Zafeiriou et al., 2000).

Following identification and diagnosis of a hearing loss, an appropriate intervention plan can be implemented and the type of amplification (hearing aids or cochlear implant) and the communication approach (aural communication or augmentative/alternative communication) can be decided on. This decision relies on precise audiometric information obtained by the audiologist. It is, however, often problematic to obtain reliable audiometric results in the CP population as various physical, perceptual and intellectual impairments may hinder the execution of certain auditory test procedures.

Within the field of Audiology, any population with special needs is referred to as a difficult-to-test population (Northern & Downs, 2002). This would include children with CP as this population presents with impairments in various developmental areas (Northern & Downs, 2002; Mechem, 2002; Newton, 1977). This population runs a higher risk for an associated hearing loss (Kolker, 2004). Therefore, the administration of a sensitive audiometric test-battery that is not influenced by various developmental impairments is needed.

Within the audiometric test-battery various auditory assessment procedures are employed to obtain specific auditory information (Roeser, 2000; Gans & Gans, 1993). Immittance measurements (tympanometry and acoustic reflexes) and otoacoustic emissions (OAEs) provide important diagnostic value to the audiological test-battery as these procedures can identify the place of lesion in the auditory pathway (Danhauer, 1997; Hall & Mueller, 1997). However, the hearing sensitivity level needs to be established in order to determine the presence of a hearing loss, and, if a hearing loss is present, the type and degree of the hearing loss.

The hearing sensitivity level is determined by obtaining hearing thresholds across the frequency spectrum of 0.25 kHz to 8 kHz. Behavioural pure tone (PT) audiometry is the first choice for hearing assessments as it is the only true test of hearing sensitivity (Folsom & Diefendorf, 1999). Subsequently, conventional PT audiometry is modified to suit the chronological and the developmental age of the child in order to elicit the best responses (Northern & Downs, 2002; Hodgson, 1994). The behavioural audiometric procedure which suits the developmental and chronological age of the child will therefore be the method of choice (Hodgson, 1994: 472).

However, the administration of behavioural audiometric procedures are influenced by the voluntary participation of the child (Yantis, 1994). Voluntary participation during behavioural PT audiometry is often compromised by factors such as poor motivation to participate, limited intelligence level (e.g. mental retardation), short attention span (e.g. hyper-attention or hypo-attention) as well sensory disabilities such as cortical blindness (Yantis, 1994). In addition, physical constraints such as involuntarily reflexes and poor head control may further constrain the voluntary participation of the child during behavioural audiometry (Mechem, 2002).

Since children with CP may typically present with a spectrum of disabilities including sensory and motor impairments as mentioned in the previous

paragraph, their ability to engage appropriately in any activity during subjective procedures may be compromised to a great extent. This inability may lead to inaccurate behavioural responses during subjective audiometric procedures. Hence, an accurate assessment of the child's hearing sensitivity may still remain difficult to obtain.

### **1.3 Rationale**

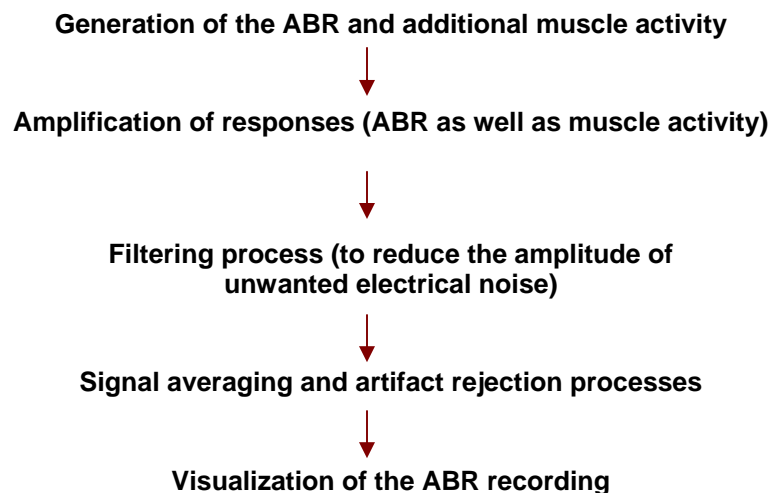
When behavioural audiometry is not possible or the validity and reliability of the results may be questioned, the audiologist needs to administer objective procedures to determine the hearing sensitivity. Objective audiometry refers to audiological procedures that are not dependent on voluntary responses from the individual being assessed, making it especially relevant for difficult-to-test populations such as children with CP (Hall & Mueller, 1997).

Auditory evoked responses (AER) are objective audiometric procedures that can be employed to determine the integrity of the auditory system (Hall, 2007; Arnold, 2000). The auditory brainstem response (ABR) is a short latency AER that is the preferred choice for auditory assessment of infants and other difficult-to-test populations (Hall, 2007; JCIH, 2007; Jiang, Andrew & Wilkinson 2006; Folsom & Diefendorf, 1999). The objectivity of the ABR, its sensitivity for the type (cochlear versus retro-cochlear pathologies) and degree of hearing loss as well as its long history and significant research database probably favour it as the current procedure of choice for difficult-to-test populations (Hall, 2007; JCIH, 2007; Jiang, Andrew & Wilkinson 2006; Arnold, 2000; Folsom & Diefendorf, 1999; Galambos, Hicks & Jo Wilson, 1984).

Being a difficult-to-test population, the CP population may, however, challenge the signal-to-noise ratio (SNR) during ABR recording. ABR recording is dependent on an adequate SNR; this implies limited interference of background noise within the frequency spectrum of the ABR (30 Hz - 3000 Hz) during the recording (Hall, 2007). However, the CP population frequently displays

involuntarily or uncontrollable muscular movements which generate myogenic potentials during the ABR recording (Hall, 2007; Workinger, 2005; Mechem, 2002). These myogenic potentials are regarded as background noise which negatively affects the SNR in two ways: firstly, the frequency spectrum of myogenic potentials (50Hz - 500Hz) overlaps with the frequency spectrum of the ABR (30Hz - 3000Hz). Secondly, the amplitude of myogenic potentials may exceed the amplitude of the vulnerable ABR which is generally between 0.1 to 1 microvolt (Hall, 2007). These two factors – interference with the frequency spectrum and exceeding the amplitude of the ABR – may ultimately lead to a poor SNR during the recording.

The improvement of a poor SNR has traditionally been addressed by modification or implementation of specific techniques on the conventional ABR system (Hall, 2007; Sanchez & Gans, 2006; Kurtz & Steinman, 2005). Conventional ABR technology incorporates certain techniques such as the amplification of the signal, inclusion of band-pass filters, signal averaging as well as artifact rejection (viewed in Figure 1.1) (Hall, 2007; Sanchez & Gans, 2006).



**Figure 1.1: Principles of conventional ABR technology**

In the case of assessing a CP child, an attempt to obtain a ‘purer’ ABR signal (i.e. improved SNR) will typically involve modifying acquisition parameters of the

conventional ABR system. Some of these modifications include increasing the amplification scale (e.g. x150 000 in stead of x100 000), increasing the low cut filter (i.e. 150Hz instead of 30Hz), using more sweeps (i.e. 2000 in stead of 1000) or employing a more conservative artifact rejection value such as 10 microvolt rather than 20 microvolt. Theoretically, these modifications will improve the SNR, provided the child is relatively quiet during testing. However, regular and extensive muscular movements, typical of the CP population, may strain the recording of the ABR to such an extent, that even maximum modification of various settings may not improve the SNR.

To compensate for the effects of the muscular movements, external patient-related methods to reduce these movements can be employed, including natural sleep, sleep deprivation or melatonin (Schmidt, Knief, Deuster, Matulat & Zehnhoff-Dinnesen, 2006; Surya, Harkera, Begentb, & Chongc, 2005). Although there are minimum risks involved when utilizing these techniques, they may not be effective in the CP population. Muscle artifacts may be present during natural sleep as children with CP may display involuntarily movements even when sleeping (Surya et al., 2005). Additionally, sleep deprivation may be impractical for parents and children; whilst the natural sleep agent, melatonin, is more effective in infants and young children (Schmidt et al., 2006).

In cases where natural sleep, sleep deprivation or the use of melatonin are inappropriate or impractical for ABR recordings in the CP population, sedation or general anaesthesia may be resorted to (Hall, 2007). Sedation or general anaesthesia will reduce body movements by manipulating the child's sleeping pattern (Surya et al., 2005). A reduction in body movements will result in minimal myogenic potentials; thus enabling the audiologist to obtain an ABR recording with an adequate SNR.

Although it seems that sedation or general anaesthesia is a relatively straightforward solution in objective audiometry, especially for a difficult-to-test



population, it is not without problems (Elwood, Hansen & Seely, 2001). Sedation, or any form of general anaesthesia, increases the risk for apnoea or airway obstruction especially in multi-handicapped and/or developmentally delayed children such as the population with CP (Schmidt, Knief, Deuster, Matulat & Zehnhoff-Dinnesen, 2006; Surya et al., 2005; Elwood et al., 2001). Hence, great care must be taken when implementing sedation and general anaesthesia in the clinical facility.

Coté and Wilson (2006) formulated recommendations in order to reduce and alleviate the risks associated with sedation or anaesthesia. The recommendations include the presence of medical supervision as well as the application of appropriate airway management equipment (Coté & Wilson, 2006). These recommendations are imperative, especially for difficult-to-test subjects or any high risk population in the clinical setting. However, considering the costs involved, it might not be practical and cost-effective in a public health care system of a developing country such as South Africa.

#### **1.4 Problem statement**

The South African public health care system is burdened by poverty and infectious diseases, e.g. HIV/AIDS. Priorities within this system include the prevention, management and cure of infectious diseases which imply that any disease that is less life threatening is regarded as secondary (Theunissen & Swanepoel, 2008). The lack of resources and expensive procedures such as anaesthesia for an ABR may be considered an inappropriate and excessive expenditure for a health system burdened by coping with acute life-threatening diseases. Alternative sedation such as chloral hydrate may be offered, though it too has an increased risk of airway obstruction, especially for the multi-handicapped CP population (Surya et al., 2005).

Considering that anaesthesia may be too expensive in the public sector and sedation still poses a risk, the applicability of the conventional ABR may be

limited in auditory assessments of difficult-to-test populations. It is obvious that the audiologist is in need of an ABR system that estimates hearing thresholds reliably – even in difficult-to-test cases where children are awake or illustrate uncontrollable and involuntary movements.

The Vivosonic Integrity™ ABR system (VS) may possibly realize this ideal as it aims to address some of the challenges faced by audiologists using the conventional ABR system (Hall, 2007; Sokolov et al., 2007). Whereas the outcome of reliable wave components of the conventional ABR systems is seriously challenged by the presence of excessive myogenic potentials, the VS ABR system proposes to be less affected by the incorporation of three novel features presented in Table 1.1. These features of the VS system were purposely designed to improve the SNR for optimal ABR recording.

**Table 1.1: Novel features of the VS ABR system**

Feature	Objective
Alternative filtering (Pre-amplification)	To improve the SNR by differentiating (filtering) between the ABR signal and myogenic potentials prior the amplification process (Hall, 2007).
Kalman filtering/averaging	To improve the SNR by adding value to the evoked responses (sweeps). Each sweep is individually considered during the averaging process and more value is awarded to signals with less noise and less value is awarded to a 'noisier' signal (Steinman & Kurtz, 2005).
Wireless recording	To eliminate electrical noises conducted from the computer or power line (Hall, 2007).

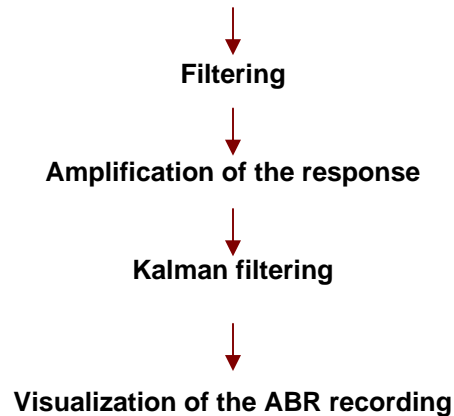
As seen in Figure 1.2, the arrangement of the filters differs from that of the conventional system (Figure 1.1). The significance of this arrangement, as explained in Table 1.1, is that evoked responses (the ABR signal as well as

myogenic potentials) are digitally filtered prior to the amplification process (Hall, 2007). The amplification process may benefit from this arrangement as contamination due to myogenic potentials and electrically conducted noises are eliminated. The elimination of the unwanted potentials reduces the risk of saturation in the first stage of the amplifier which enables the audiologist to optimize the gain of the amplifier (Hall, 2007). As the amplifier is positioned at the electrode site (rather than at a distance like the arrangement of conventional ABR systems), the quality of the ABR response may further be optimized.

In addition to the alternative arrangement of the filters and the location of the amplifier, Kalman filtering may offer another advantage for improving the quality of the ABR recording, especially in the presence of sporadic myogenic potentials (Kurtz & Steinman, 2005). Kalman filtering is an alternative weighting averaging technique (algorithm) which promises to minimize the effects of muscular activity during the ABR recording (Hall, 2007; Kurtz & Steinman, 2005). Kalman filtering has been designed to evaluate each sweep (stimulus repetition) individually during the averaging process and to add a certain value accordingly – more value is awarded to signals with less noise and less value is awarded to a 'noisier' signal (Kurtz & Steinamn, 2005). By using this information an estimate of the ABR is produced. In this estimated ABR the likelihood of error in the amplitude estimate at each latency point is minimized (Hall, 2007). Thus, with the inclusion of the Kalman filtering technique, the adverse effects of sporadic myogenic potentials are reduced (Hall, 2007; Steinman & Kurtz, 2005). This suggests that ABR recordings might be more feasible in the CP population when using the techniques provided by the VS system as compared to techniques used in conventional ABR systems.

The research question this study therefore proposes is: ***What is the clinical utility of the Vivosonic Integrity ABR system in children with Cerebral Palsy?***

**Generation of the ABR and additional muscle activity**



**Figure 1.2: Alternative setting arrangement of the VS ABR system**

## **1.5 Outline of the chapter contents**

The current dissertation provides an in-depth description of the procedures followed to address the research question as described in this chapter. Table 1.2 provides a concise summary of the content of each of the chapters of the dissertation.

## **1.6 Conclusion**

Auditory assessments in the CP population might be challenging due to the occurrence of various disabilities including physical and cognitive disabilities. The ABR is favoured as the current procedure of choice to assess auditory functioning in difficult-to-test populations. However, the applicability of the conventional ABR system is often limited with populations who present with involuntarily reflexes or spasms such as the CP population. The inclusion of the novel features of the VS system may alleviate the effects of involuntarily reflexes or spasms which produce large myogenic potentials (Hall, 2007; Steinman & Kurtz, 2005). If proven to be successful, the novel features of the VS ABR system could be a valuable way to improve the in which difficult-to-test populations are assessed. Reducing the need for anaesthesia or sedation may save expenditures and, more importantly, the risks associated with these procedures are avoided.

**Table 1.2: Summary of dissertation contents by chapter**

<b>Chapter 1</b>	<i>Introduction and Orientation:</i> This chapter provides an overview of the CP condition and the need to identify a hearing loss in the CP population. The challenges to identify and diagnose a hearing loss in this population by means of various audiological procedures, including the ABR, are also briefly discussed. The novel VS ABR system is contrasted to the conventional ABR system to assess auditory functioning in the CP population. This delineates the purpose of the study, to determine the clinical utility of the VS ABR system when assessing auditory functioning in children with CP.
<b>Chapter 2</b>	<i>A Critical Perspective on Auditory Assessment in the Cerebral Palsy Population:</i> This chapter discusses the CP condition extensively and emphasizes the importance of early identification of a hearing loss in this population. The challenges to reliably identify auditory functioning in the CP population are discussed extensively. The ABR procedure is discussed as the most widely used auditory evoked response for determining auditory functioning and estimating hearing thresholds in difficult-to-test populations. A critical discussion of the conventional ABR serves as an introduction to the discussion of the VS ABR system with novel technology that has become available. Theoretical and clinical advantages of how the VS ABR system might address the limitations of the conventional ABR system are provided.
<b>Chapter 3</b>	<i>Methodology:</i> This chapter describes the operational framework implemented to conduct the empirical research. This chapter includes the aims of the study, the research design, ethical considerations, research sample, material, apparatus, procedures as well as the validity and reliability of the research.
<b>Chapter 4</b>	<i>Results:</i> The results of the empirical research are presented in this chapter.
<b>Chapter 5</b>	<i>Discussion:</i> This chapter provides an interpretation of the results obtained in Chapter 4. The meaning and the significance of the results obtained is discussed extensively and compared against previous research studies.
<b>Chapter 6</b>	<i>Conclusions and Recommendations:</i> This chapter infers conclusions on the findings of the study. A critical evaluation of the current study is provided. Recommendations for further research are made in light of the findings of the current study.

## 1.7 Summary

This chapter provided an overview of the CP condition and the importance of identifying and diagnosing a co-occurring hearing loss in this population. The ABR was briefly discussed as the preferred procedure for assessing auditory functioning in this population. Novel ABR technology in the VS ABR system was briefly compared to conventional ABR technology. Theoretical and clinical advantages of how the VS ABR system might address the limitations of conventional ABR technology have been indicated. An outline of the chapter contents was also provided.

## Chapter 2

# A CRITICAL PERSPECTIVE ON AUDITORY ASSESSMENT IN THE CEREBRAL PALSY POPULATION

*The aim of this chapter is to provide a theoretical foundation for the empirical research and to provide a critical evaluation and interpretation of the relevant literature.*

### 2.1 Introduction

The population with cerebral palsy (CP) not only displays a cluster of motor disorders, but often present with associated disorders such as hearing loss as well (Mechem, 2002). Within the field of Audiology, this population is regarded as a difficult-to-test population (Northen & Downs, 2002). The high incidence of hearing loss in the CP population stresses the importance of accurate, efficient and risk-free auditory procedures.

### 2.2 Background to cerebral palsy

The following section is dedicated to the background of CP and its classification, as well as its general prevalence and its specific prevalence in the South African context.

#### 2.2.1 Historical perspective on cerebral palsy

The recorded history of CP dates back to eras before Christ when physical impairments, some of which might be referred to as CP, were depicted and described through Egyptian carvings and were recorded in both Greek and Hebrew scriptures (Scherzer, 2001; Newton, 1977). Figure 2.1 illustrates an Egyptian carving of an individual with right hemiplegia dating back to 5 BC. Throughout history CP has been communicated, described and illustrated in various forms of art and literature: during the medieval and Renaissance periods artists such as Raphael and Nicolas Poussin illustrated the crippled and the

palsied through paintings (Newton, 1977) and in Elizabethan times William Shakespeare mentioned this condition in his play Richard III (Scherzer, 2001).



**Figure 2.1: Egyptian carving of a person with right hemiplegia**

Adapted from: Scherzer (2001:2)

It was, however, only in the 19<sup>th</sup> century that the modern day understanding of CP was established when French orthopaedist, Delpech, expressed his interest in this condition after which the English surgeon, William John Little, described its symptoms in 1843 (Scherzer, 2001). Subsequently, CP has often been referred to as *Little's Disease* (Lawson & Badawi, 2003; Newton, 1977).

Few connected this condition to a lack of oxygen during birth and suggested that these children were affected during the first year of life (Wilson-Jones, Morgan, Shelton & Thorogood, 2007). In 1897 Sigmund Freud suggested that CP might be due to insufficient brain development prior to birth and related the child's abnormal development to factors influencing the developing foetus (Wilson-Jones et al., 2007). Both Little and Freud made valuable contributions to our understanding of the nature of this disorder as it is known today; yet it was only in the 1930-50's that Winthrop Phelps, an orthopaedic surgeon, described the cluster of symptoms (i.e. a combination of motor and sensory disturbances)



which laid the foundation for more comprehensive definitions of and perspectives on CP (Mechem, 2002; Newton, 1977).

### **2.2.2 Prevalence and definition of cerebral palsy**

CP has been acknowledged as a universal phenomenon with a prevalence of between 2 to 4 per 1000 live births (Andersen et al., 2008; Jeseja, 2008; Donnely et al., 2007; Fawke, 2007; Beckung & Hakung, 2002; Hutton & Pharoa, 2002; Winter, Autry, Boyle & Yeargin-Allsopp, 2002). Some authors have reported that the prevalence of CP has remained constant for approximately 40 years despite technological advances that decrease mortality in term as well as preterm infants (Wilson-Jones et al., 2007; Lawson & Badawi, 2003). Others have argued that the prevalence of CP in especially low birth weight infants has increased over a period of 10 to 20 years (Winter et al., 2002). This might be attributed to improvements in neonatal care and obstetric services which may lead to increased survival of high risk infants, even where CP might be present (Fawke, 2007).

The awareness of a possible increase in the prevalence of this condition highlights the need for further research in the development of appropriate assessment and intervention procedures. However, prior to the implementation of assessment and habilitation services, the term *cerebral palsy* needs to be clarified and appreciated by medical personnel, family other individuals involved.

CP has been defined by various researchers at different stages over past decades and subsequently many definitions of this condition have been proposed (Andersen et al., 2008; Donnely et al., 2007; Lawson & Badawi, 2003; Hutton & Pharoah, 2002; Kennes et al., 2002; Mechem, 2000; Zafeiriou, Andreou & Karasavidou, 2000; Stanton, 1992; MacDonald, 1987; Newton, 1977; Minear, 1956). Definitions found in literature focus mainly on three characteristics of CP: the static nature of the condition, the fact that it manifests as a motor impairment as well as the fact that this condition is due to an insult to the immature brain

(Donnely et al., 2007; Wilson-Jones et al., 2007; Kennes et al., 2002; Stanton, 1992; MacDonald, 1987; Newton, 1977; Minear, 1956). Considering all three characteristics, this condition was defined by the International Working Group on Definition and Classification of Cerebral Palsy in 2004 as “...a group of permanent disorders of the development of movement and posture, causing activity limitation, that are attributed to non-progressive disturbances that occurred in the developing fetal or infant brain” (O’Shea, 2008:36).

The above definition clearly states that any insult to the immature brain may cause CP. Any congenital (i.e. prior, during or directly after birth) or acquired (e.g. during childhood) insult that disrupts the anatomical and physiological maturation of the brain can be referred to as a risk factor for CP (Workinger, 2005).

### **2.2.3 Risk factors associated with cerebral palsy**

The aetiology of CP may include a number of risk factors even though 40% to 50% of cases currently diagnosed with CP have no known causes (Wilson-Jones, 2007; Mechem, 2002; Stanton, 1992; Newton, 1977). Generally, the aetiology of CP is categorized into three groups that reflect the risk factors during the prenatal period (i.e. prior labour), the perinatal period (i.e. from birth to the first week of life and the postnatal period (i.e. after the first week of life until the developing brain has matured) (Wilson-Jones et al., 2007; Lawson & Badawi, 2003).

It seems that the risk factors responsible for the majority of CP cases include problems during intrauterine development, intrauterine infection such as rubella, congenital disorders, asphyxia (occurring in any gestational period), hyperbilirubinemia and prematurity (Wilson-Jones, 2007; Willoughby & Nelson 2002). Problems during intrauterine development, intrauterine infection and asphyxia have been accepted by various researchers as established and consistent risk factors for CP (Wilson-Jones, 2007; Workinger, 2005; Lawson &

Badawi, 2003; Cogher et al, 2002; Mechem, 2002; Willoughby & Nelson, 2002; McDonald, 1987). However, it appears that inconsistent data exists regarding the incidence of prematurity causing CP. According to Andersen et al. (2008) prematurity accounts for 12% of the CP population, whereas Wilson-Jones, Morgon, Shelton & Thorogood (2007) and Mechem (2002) considered prematurity (birth prior to 37 weeks gestational age) to be the causative factor in 25 to 40% of the CP population in the United States (US) and Sweden. This high incidence of prematurity resulting in CP could be accurate considering the higher susceptibility of premature infants for developing high risk conditions such as asphyxia and hyperbilirubinemia (Mechem, 2002). Thus, the presence of high risk conditions may be seen as contributing factors for acquiring CP during prematurity.

Understanding the contributing risk factors for CP remains complex. A single factor may be insufficient to cause cerebral damage, but if the same factor is present to an overwhelming degree, it may cause CP (Lawson & Badawi, 2003). In addition, multiple causes may be responsible for the irreversible brain injury in CP (Lawson & Badawi, 2003). Nevertheless, knowledge of aetiologies is imperative for diagnostic and rehabilitative purposes because the type of CP often correlates with a specific aetiology and can be classified according to specific symptoms. Different risk factors play a role in the various periods and are summarized in Table 2.1.

#### **2.2.4 Classification of cerebral palsy**

Similar to the greatly varying aetiology, the presentation of the various disabilities is unique to each child (Stanton, 1992). Throughout the decades a number of attempts have been made to construct/develop a method to classify the various presentations of disabilities (Workinger, 2005; Stanton, 1992; McDonald, 1987, Newton, 1977; Minear, 1956).

**Table 2.1: Risk factors associated with CP**

Prenatal risk factors	Perinatal risk factors	Postnatal risk factors
❖ Maternal neurological disorders/diseases	❖ Asphyxia	❖ Asphyxia
❖ Infertility treatment	❖ Premature birth (< 28 weeks)	❖ Seizures within 48 hours of birth
❖ Thyroid disease	❖ Low birth weight (< 2500 g)	❖ Cerebral infarction
❖ Hypoxia	❖ Blood incompatibility	❖ Hyperbilirubinemia
❖ Metabolic disorders	❖ Infection e.g. meningitis	❖ Sepsis
❖ Multiple gestation	❖ Abnormal foetal presentation	❖ Respiratory distress syndrome/chronic lung disease
❖ Intrauterine infections e.g. cytomegalovirus (CMV), rubella	❖ Placental abruption	❖ Infection e.g. meningitis
❖ Thrombophilic disorders	❖ Instrument delivery	❖ Intraventricular hemorrhage
❖ Teratogenic exposure	❖ Toxoplasmosis	❖ Periventricular leukomalacia
❖ Chorioamnionitis	❖ Hyperbilirubinemia	❖ Shaken baby syndrome
❖ Maternal fever		❖ Head trauma
❖ Exposure to toxins		
❖ Malformation of brain structures		
❖ Intrauterine growth restriction		
❖ Abdominal trauma		
❖ Vascular insults		

Adapted from: Wilson-Jones (2007); Lawson & Badawi (2003); Cogher et al. (2002); Mechem (2002); Sheykhleslami & Kaga (2000); Stanton (1992); Newton (1977)

In the early 19<sup>th</sup> century, Sigmund Freud proposed a broad spectrum classification which primarily described the visible neuro-muscular symptoms which included hemiplegia, general cerebral spasticity, paraplegic spasticity, centralized chorea, bilateral athetosis and bilateral spastic hemiplegia (Shoup & Roeser, 2000; Stanton, 1992). Although this classification manner of classification merely described the orthopaedic aspect of the condition, it created a platform for researchers such as Minear (1956) to produce a more

comprehensive classification that involved neurological as well as orthopaedic perspectives on CP.

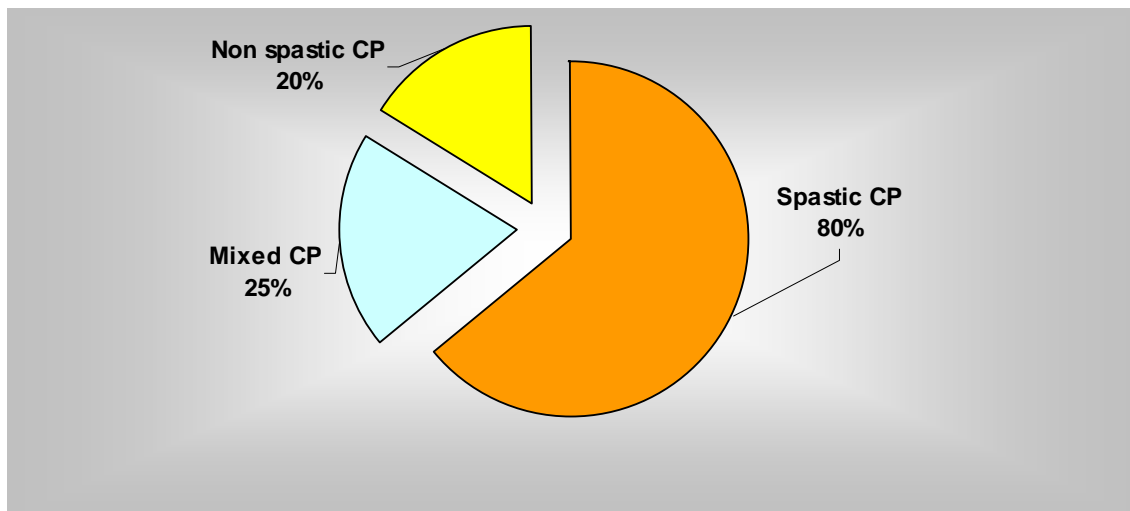
Recent literature refers to two different approaches that are employed to categorize CP (Wilson-Jones, et al., 2007). The first approach divides CP into two categories according to the predominant motor impairment (e.g. spasticity, athetotic or hypotonic) and the topographical pattern of limb movement (e.g. monoplegia, diplegia or quadriplegia) which are involved (Wilson-Jones, et al., 2007). The second approach to categorize CP focuses not only on predominant motor impairments, but also on the area of brain lesion (Wilson et al., 2007). Two main physiological categories, i.e. pyramidal (spastic) and extra-pyramidal (non-spastic) serve as the foundation from which various subtypes such as athetosis and hemiplegia are identified. This approach is summarized in Table 2.2.

**Table 2.2: Classification of CP**

Main types of CP	Brain lesion	Subtype	Characteristics
<b>Spastic</b>	<i>Pyramidal lesion</i>	Monoplegia Diplegia Triplegia Quadriplegia	Lower (pathological) threshold of stretch reflex.  Increased muscle tone which can lead to contractures
	Cortico-spinal lesion (upper motor neurons)		
<b>Non-spastic</b>	<i>Extra-pyramidal lesion</i>		Incontrollable and/or involuntarily movements
	1) Basal ganglia lesion/thalamus (deep motor neurons)	1) Dyskinetic: Athetosis and dystonia	Possible difficulty in initiating voluntarily movement  Hearing and visual impairments common
	2) Damage to neurons in cerebellum	2) Ataxic	Disturbance in sense of balance and equilibrium

Adapted from: Wilson-Jones (2007); Cogher et al. (2002); Mechem (2002); McDonald (1987); Newton (1977)

The spastic type of CP accounts for the majority of the CP population (70% to 80%) as demonstrated in Figure 2.2 (Wilson-Jones et al., 2007; Cogher et al., 2002; Mechem, 2002). This type of CP is occasionally referred to as upper motor neuron damage and is caused by damage to the cortex and/or the cortico-spinal pathways (Wilson-Jones, 2007; Cogher et al., 2002; Mechem, 2002). Any part of the body could be involved in spastic CP, resulting in paraplegia, hemiplegia, triplegia or quadriplegia could result (Cogehr et al., 2002). The main characteristic of this group is the presence of an exaggerated stretch reflex as well as increased muscle tone which can ultimately lead to contractures (O'Shea, 2008; Workinger, 2005; Mechem, 2002).



**Figure 2.2: Distribution of the main CP types**

Adapted from: Wilson-Jones (2007); Cogher et al. (2002); Mechem (2002)

Contrary to the increased muscle tone of the spastic group, non-spastic CP is characterized by incontrollable and involuntarily (athetoid and dystonic CP) or disturbances related to kinesis and/or balance and the in-coordination of the movements (ataxic CP) (Workinger, 2005; Cogher et al., 2002; Mechem, 2002; Stanton, 1992). The non-spastic group comprises of the athetoid, dystonic and ataxic types of CP and accounts for approximately 5% to 15% of CP cases as presented in Figure 2.2 (Wilson-Jones, 2007). Athetoid, dystonic and ataxic CP are caused by extrapyramidal lesions due to damage to the basal ganglia, the

deep motor neurons of the thalamus or the cerebellum (Cogher et al., 2002; Mechem, 2002; Stanton, 1992). The functions of these brain structures focus on the regulation of movement. Consequently, damage to these structures may cause difficulties in terms of this regulation.

Although spastic and non-spastic CP are the main types, a combination between these two CP types may occur which is referred to as mixed CP (Mechem, 2002). In fact, it appears that this group accounts for approximately 25% of the total population as illustrated in Figure 2.2 (Mechem, 2002) and displays characteristics of both main types (Mechem, 2002). The precise classification of children with a mixed form of CP remains a challenge as different brain lesions bring forth diverse disabilities (Andersen et al., 2007). In such cases, the predominant motor symptoms may determine the classification, though accompanied symptoms need to be addressed in the intervention process (Minear, 1956).

By categorizing the symptoms of this complex entity an appropriate intervention plan can be compiled accordingly. Thus, the classification of CP remains imperative for each clinical setting worldwide, also in the South African context where the prevalence of CP seems significant.

### **2.2.5 Cerebral palsy in the South African context**

CP is a universal phenomenon that does not discriminate between races or cultures (Andersen, 2008; Winter, 2002; Arens & Moltano, 1989). Although the prevalence of CP has not been established in developing countries such as South Africa, it appears to be significantly higher, up to five times, compared to the estimated prevalence of 2 to 4 per 1000 live births in developed countries, e.g. Ireland, US and Sweden (Donnelly et al., 2007; Fawke, 2007; Couper, 2005; Winter, Autry, Boyle & Yeargin-Allsopp, 2002).

A number of recent studies provided valuable insight into the occurrence of CP in different regions of South Africa (Couper, 2002; Christianson et al., 2002). Research conducted in a rural in the Limpopo province indicated that 8.4% of children assessed at primary health care institutions presented with CP (Christianson et al., 2002). Couper (2002) reported a prevalence of 10 per 1000 children presenting with CP in a rural area in the Kwazulu-Natal province. Although these findings are representative of only two rural areas in South Africa, it seems that the prevalence of CP is rather substantial.

Explanations for the higher CP prevalence rates in developing countries are not entirely clear (Couper, 2002), though it has been argued that socio-economic factors could play a significant role (Arens & Molteno, 1989). In South Africa, the socio-economic situation is adversely affected by challenges such as poverty and HIV/AIDS (Theunissen & Swanepoel, 2008). Poverty is the cause of undesirable living conditions such as overcrowding, malnutrition, poor hygiene and tuberculosis which are contributory factors that could lead to widespread diseases such as meningitis (Cooper, 2002; Stanley, Blair & Alberman, 2002; Arens & Molteno, 1989). If not treated timeously and effectively, these diseases can be a potential causative factor for CP acquired in childhood years prior to brain maturation (Arens & Molteno, 1989).

Whilst poverty can indirectly be a potential causative factor for postnatally acquired CP, the presence of HIV/AIDS affects the child directly and can result in pre-, peri- or postnatally acquired CP (Mitchell, 2001). The HI-virus has extensive medical consequences in the paediatric population, including the presence of CP as a secondary sequel. UK-based research illustrated that 29% of children with paediatric HIV/AIDS presented with CP (Cooper, Lyall, Walters, Tudor-Williams, Habibi, De Munter, Britto & Nadel, 2003). This is not surprising as in-utero infections such as cytomegalovirus (CMV) or toxoplasmosis, premature birth or low birth weight that are all closely associated with HIV (Newell, 1998) are also confirmed risk factors for CP (Lawson & Badawi, 2003;



Cogher et al., 2002; Mechem, 2002; Willoughby & Nelson, 2002; Sheykholeslami & Kaga, 2000; Stanton, 1992; Newton, 1977).

In the South African context, HIV/AIDS and poor socio-economic conditions are but a few factors contributing to the high prevalence of CP. The reality that confronts medical professionals is not only to identify the children presenting with CP (despite their HIV-status), but also to manage the condition inclusive of its widespread effects on development including speech, language and hearing.

### **2.3 Cerebral palsy and hearing loss**

CP is one of many childhood disabilities that not only compromises general motor development, health status and general behaviour of a child; but is also associated with secondary impairments (Donnely, Parks, McDowell & Duffy, 2007; Lawson & Badawi, 2003; Kennes, Rosenbaum, Hanna, Walter, Russell, Raina & Galuppi, 2002; Mechem, 2002; Cogher, Savage & Smith, 1992; Newton, 1977). Norwegian data illustrated that only 28% of children presenting with CP have been diagnosed without any associated impairments (Andersen, Irgens, Haagaas, Skranes, Meberg & Vik, 2008). Secondary impairments include epilepsy, intellectual impairments or mental retardation, perceptual impairments and sensory impairments (vision and hearing disabilities) (Andersen et al., 2008; O'Shea, 2007; Lawson & Badawi, 2003; Kennes et al. 2002; Mechem, 2002; Stanton, 1992; Newton, 1977).

The population with CP seems to present a higher incidence or occurrence of hearing loss than the normal population as is illustrated in Table 2.3 (Sano et al., 2005; Kolker, 2004; Russman & Ashwal, 2004; Shapiro, 2003; Mechem, 2002; Sheykholeslami & Kaga, 2000; Northern & Downs, 1991; McDonald, 1987; Newton, 1977).

**Table 2.3: Incidence of hearing loss in the CP and normal populations**

Estimated % of hearing loss in CP population	Estimated % hearing loss in infants in Sub-Saharan Africa (no CP cases)	Estimated % hearing loss in infants in industrialized areas (no CP cases)
11% Newton (1977)	0.006% Swanepoel & Storbeck (2008)	0.002% -0.004% (Olusanya, 2008)
0.3% - 3.7% Kennes et al. (2002)		
4% -25% Kolker (2004)		
0.8%-6% Fawke (2007)		

The discrepancies that exist between the incidence percentages shown in Table 2.3 could be attributed to a number of reasons (Newton, 1977). Firstly, the criteria for judging the presence of hearing loss were not the same for all studies. If specific criteria for a hearing loss was 0.5 kHz to 4 kHz, and some children presented with a high frequency loss that fell above the speech frequency range (that would imply a hearing loss between 6 kHz to 8 kHz), those children would have been excluded from the incidence numbers that were measured. Secondly, throughout the decades, different types of hearing assessment procedures were used. Initially, behavioural audiometry by means of behavioural observations and a psychogalvanometer which both depended on conditioned responses (Byers et al., 1955) were used to detect a hearing loss. Finally, Newton (1977) commented on the variation that exists regarding the skills of different examiners (the audiologists) in choosing the most appropriate audiological procedures and at the same time considering the age of the child, the severity of the condition as well as associated impairments. A child with CP may wrongly be diagnosed with a hearing loss or, alternatively, may be misdiagnosed as presenting no hearing loss due to the difficulty in obtaining accurate behavioural test results (Shoup & Roeser, 2000).

Though the specific cause for the presence of a hearing loss in the CP population is not entirely clear, many of the risk factors are shared, for example hyperbilirubinemia due to erythroblastosis fetalis (often associated with Rh-incompatibility), rubella, prematurity, low birth weight, asphyxia, meningitis, toxoplasmosis and/or CMV (Sano et al., 2005; Shapiro, 2003; Parker & Parker, 2002; Nakamura, Takada, Shimabuku, Matsuo, Matsuo & Negishi, 1985; Newton, 1977; Byers et al., 1956). Toxoplasmosis, CMV, bacterial meningitis and rubella have generally been accepted as established risks for the presence of a congenital or an acquired sensorineural hearing loss in the population without CP (Stein & Boyer, 1994), although a relationship between these risk factors and a hearing loss in the population with CP has not yet been established. However, it seems that these risk factors are the most apparent cause of a hearing loss in the CP population. Hearing loss therefore appears to be subjected to the same risk factors that predispose CP and is not directly associated with the CP as such.

The majority of the risk factors mentioned above may be responsible for damage to cochlear structures which lead to the assumption that a sensory hearing loss is the main type of hearing loss in the CP population (Sano et al., 2005; Sheykholeslami et al., 2000). However, middle ear pathologies, in particular otitis media, are among the most common childhood diseases (Orlin, Effgen, Handler, 1997) This holds true for the CP population as well (Newton, 1977). Thus, the presence of otitis media needs to be constantly monitored for especially since it may be difficult for the CP child to communicate common symptoms (e.g. otalgia) associated with the condition.

Additionally, the presence of another type of hearing loss, i.e. auditory neuropathy spectrum disorder (ANSD), must also be kept in mind. ANSD may be the result of damage to the inner hair cells of the cochlea or dysynchrony of the synapse of the cochlea and the auditory nerve (Romero, Mendez, Tello &

Torner, 2008; Ngo, Tan, Balakrishnan, Lim & Lazaroo, 2006; Sano et al., 2005; Shapiro, 2003; Sheykhholeslami et al., 2000; Nakamura et al., 1985).

Various factors including prematurity and neonatal hyperbilirubinemia may contribute to the presence of ANSD (Hall, 2007; Shapiro, 2003). Prematurity and neonatal hyperbilirubinemia are also risk factors for a sensory hearing loss (Shapiro, 2003) which stresses the importance of a careful and accurate differential diagnosis by the audiologist.

Differentiating between the types of hearing loss is extremely important as the selection of an intervention mode will be based on the type of hearing loss. The child with a middle ear pathology will be referred for an appropriate medical examination whilst the child with a sensory hearing loss or ASND will be a candidate for specific amplification (hearing aids or cochlear implants) and speech therapy (aural rehabilitation and/or augmentative or alternative communication) depending on the severity of the hearing loss and other impairments.

In the general population differential diagnosis usually is a straightforward and uncomplicated process. However, the complex, multi-faceted condition of CP presents challenges for differential diagnosis. Differential diagnosis may be demanding since the audiologist is not confronted with the presence of a hearing loss only, but with a spectrum of disabilities including motor, cognitive, perceptual, speech, and language disabilities (Wilson-Jones et al., 2007; Workinger, 2005; Cogher et al., 2005; Mechem, 2002; Stanton, 1992).

The audiologist needs to overcome these challenges when assessing auditory functioning of a child with CP. Early identification of a hearing loss and the implementation of appropriate intervention could make a significant difference in the CP child's life and could result in the child living life to his/her optimum potential, given the physical and/or cognitive constraints.

## **2.4 Importance of early identification of hearing loss in children with cerebral palsy**

The CP population is a vulnerable group with a high risk for global developmental delay as well as additional hearing loss (Workinger, 2005; Newton, 1977). If the additional hearing loss is not timeously intervened, it may compromise the global development to an even greater extent.

Research has demonstrated the adverse effects of a hearing loss on the global development (including communication, cognitive, motor and emotional abilities) in populations without any secondary disabilities such as CP (Olusanya, 2008; Sininger et al, 1999; Yoshinaga-Itano, 1998). To avoid or minimize these negative effects, early identification of a hearing loss followed by early intervention is recommended (Downs & Yoshinaga-Itano, 1999; Singerer et al, 1999). The efficacy of early intervention following early identification and diagnosis of a hearing loss has been convincingly demonstrated (Driscoll et al. 2002; Zafeiriou, 2000; Singer, Doyle & Moore, 1999; Downs & Yoshinaga-Itano, 1999; Yoshinaga-Itano, 1998) advantageous to children with and without disabilities.

By reducing the contributing speech and language impairments, the disabled child may participate in a community more actively and independently, resulting in improved quality of life outcomes. Quality of life is the ultimate goal for a disabled child as stated by the UN Convention on the Rights of the Child (1989). Since research has proven that the CP population survive well into adulthood (Hemming et al., 2005; Beckung & Hagberg, 2002; Bottos, Feliciangeli, Sciuto, Gericke & Vianello, 2001), it is essential that the child's communication abilities (language and hearing) are maximized to ensure optimal functioning in their environment. In order for this goal to be realised, a communication mode needs to be introduced and implemented. The foundation of these interventions, however, remains the accurate and reliable assessment of hearing abilities.

## **2.5 Auditory assessment and cerebral palsy**

In the CP population the entire auditory pathway is at risk for a congenital or acquired hearing loss (Fawke, 2007; Sano, 2005; Kolker, 2004; Northern & Downs, 2002). The type, degree and configuration of the hearing loss need to be determined in order for appropriate habilitation to commence. Thus, a comprehensive auditory assessment which comprises of behavioural and objective assessments, and which reveals reliable results, is of great importance.

### **2.5.1 Behavioural audiometry and cerebral palsy**

Behavioural audiometry is the preferred choice in hearing assessment as it is the only true test of hearing (Folsom & Diefendorf, 1999). The philosophy of behavioural audiometry is based on specific responses, unconditioned or conditioned, obtained from the individual being assessed (Hodgson, 1994). The behavioural audiometry procedure will determine the type of responses that will be elicited.

An unconditioned response procedure such as behavioural observation audiometry (BOA) does not require voluntarily participation and the results are based on the elicitation of unconditioned responses such as the startle reflex or sound localization (Hodgson, 1994). Thus, it may be assumed that this procedure can be followed in auditory assessments of populations who are difficult to condition due to various factors such as cognitive or physical disabilities. However, this procedure demonstrates limited diagnostic applicability as it is a test of auditory responsiveness only (Gans & Gans, 1993) and neither frequency nor ear specific information can be obtained (Northern & Downs, 2002). In an attempt to compromise for these limitations, conditioned response procedures are employed.

Conditioned response procedures which include conventional pure tone (PT) audiometry, visual response audiometry (VRA) and conditioned play audiometry (CPA) are standard behavioural procedures to determine frequency and ear

specific auditory sensitivity (Driscoll et al., 2002; Yantis, 1994). Although the age as well as the developmental level of the client needs to be considered in order to administer the most appropriate behavioural procedure (Folsom & Diefendorf, 1999), the term *conditioned responses* implies that the child's cooperation is expected in order to obtain reliable PT results, whether it be a head turn or an eye movement.

Voluntary participation and cooperation to conduct the behavioural procedure are, however, not always possible. Voluntary cooperation is especially challenging with CP clients where a variety of complex behaviours such as motor disabilities (e.g. poor head control, spasticity or involuntarily movements), cognitive impairments (e.g. mental retardation), perceptual problems (e.g. short attention span and/or hyperactivity) and visual impairments (e.g. cortical blindness) may be present (Mechem, 2002, Cogher et al. 1992; Stanton, 1992). These associated disabilities may impede voluntary and consistent cooperation (Vlaskamp & Cuppen-Fonteine, 2007) which may interfere with the administration of behavioural PT assessments and ultimately poses a potential threat to the reliability of the audiogram (Vlaskamp & Cuppen-Fonteine, 2007). From Table 2.4 it is clear that associated motor and cognitive impairments were the main obstacles in the way of obtaining reliable behavioural PT results in children with CP.

From the perspective of paediatric audiology where reliable audiometric information is imperative, behavioural audiometry may be unreliable and non-specific (Picton, 1991). This statement may be especially true for assessments of difficult-to-test populations such as CP where false negative or positive responses complicate the establishment of audiometric thresholds. Routine behavioural hearing assessments (follow-up assessment, for example every 6 weeks) could be argued for as an alternative approach to obtain the necessary audiometric thresholds.

**Table 2.4: Outcomes of behavioural audiometric techniques in the CP population**

Author	Behavioural audiometric technique	Outcome
Sano et al. (2005)	Behavioural PT audiometry and BOA	67% of the subjects could not be tested with either behavioural audiometric techniques due to cognitive impairments or motor dysfunction
Topolska et al. (2002)	Behavioural PT audiometry	75% of the subjects could not be tested due to the cognitive impairments
Driscoll et al. (2000)	Behavioural PT audiometry	50% of the subjects with moderate to severe developmental retardation could not be tested
Benham-Dunster & Dunster (1985)	Behavioural PT audiometry, VRA and BOA	75%, 20% and 5% of moderately delayed subjects were tested with behavioural PT audiometry, VRA and BOA respectively. 11%, 39% and 50% of profoundly delayed subjects were tested with behavioural PT audiometry , VRA and BOA respectively

Two problems, however, may arise when following this approach. Firstly, some children might never be able to participate voluntarily due to immaturity of the central nervous system which is reflected in developmental delays in various



areas including motor development (Folsom & Diefendorf, 1999). Secondly, obtaining frequency-specific audiometric information (i.e. 0.5 kHz to 8 kHz) may take several sessions. This suggests that the presence of a hearing loss may only be identified in the second or third follow-up session, thus delaying the diagnosis of the impairment. Since the Joint Committee on Infant Hearing (JCIH) (2007) recommends that infants and children receive intervention as early as possible, any delay in the identification and diagnosis of a hearing loss can be regarded as an obstacle in the early intervention process (Yoshinago-Itano, 1998).

Providing appropriate amplification (e.g. hearing aids, cochlear implants) is an important part of the intervention process and depends largely on accurate diagnostic audiometric results. Hence, the audiologist working with the difficult-to-test population needs a testing instrument to identify and characterize a hearing loss in this population that either complements behavioural audiometry or replaces it. Objective audiometric measures are typically relied on in such cases.

### **2.5.2 Objective audiometry and cerebral palsy**

Behavioural conditioning of difficult-to-test populations to sound field auditory stimuli is not feasible, hence there is a need for objective audiometric procedures (Folsom & Diefendorf, 1999; Hodgson, 1994). Immittance measurements (tympanometry and acoustic reflexes), otoacoustic emissions (OAEs) and auditory evoked responses (AER) provide the audiologist with important diagnostic information. These procedures are objective and relatively easy to perform, enhancing their functionality in auditory assessments of difficult-to-test populations such as the population with CP (Margolis & Hunter, 2000; Palmu et al., 1999; Danhauer, 1997; Hall & Mueller, 1997). Each procedure focuses on the functionality of a specific section of the auditory pathway and therefore is collectively known as place of lesion tests (Danhauer, 1997; Hall & Mueller, 1997).

Tympanometry and acoustic reflexes provide diagnostic information regarding the status and integrity of the middle ear (Margolis & Hunter, 2000; Palmu et al., 1999). When assessing auditory functioning in difficult-to-test populations such as CP these procedures fulfil an important part of differential diagnosis in particular. Tympanometry is especially useful in identifying the presence of otitis media with its high incidence in intellectually and multi-handicapped children – higher than in the normal population (Driscoll et al., 2002; Mechem, 2002). In addition, acoustic reflex testing objectively predicts frequency-specific pure tone thresholds (Northern & Gabbard, 1994). The use of these immittance measurements is extremely valuable, though it does not provide any information regarding the integrity of the cochlea.

Otoacoustic emission (OAE) measurements provide physiological information about the functioning of the cochlea, specifically regarding the integrity of the outer hair cells of the organ of Corti (Sano et al., 2005; Hood & Berlin, 2002; Norton & Stover, 1994; Durrant, 1992). Several types of OAEs can be recorded, though the most commonly used in research and clinical settings are Distortion Product Otoacoustic Emissions (DPOAEs) and Transient Evoked Otoacoustic Emissions (TEOAEs) (Danhauer, 1997). Both DPOAEs and TEOAEs are sensitive to non-pathological factors such as body movements (Venter, 2000). Excessive body movements create internal noise that influences the recording of the OAE negatively (Baer & Hall, 1992). Children with CP display a fair amount of internal noise, whether it is due to spastic contractures, involuntary or uncontrollable body movements (Workinger, 2005). Venter (2000) particularly noted that body movements had a great effect on OAE measurements in children with CP. Thus, OAE measurements may be difficult to obtain, or might not be obtainable at all in children with severe involuntary or uncontrollable body movements.

Despite the fact that OAEs may be difficult to measure due to non-pathological subject factors, the inclusion of OAE as well as immittance measurements in the

diagnostic audiological test battery remains essential. However, the audiologist can not solely rely on these procedures as hearing levels can not be quantified and hearing thresholds in dB HL are still required.

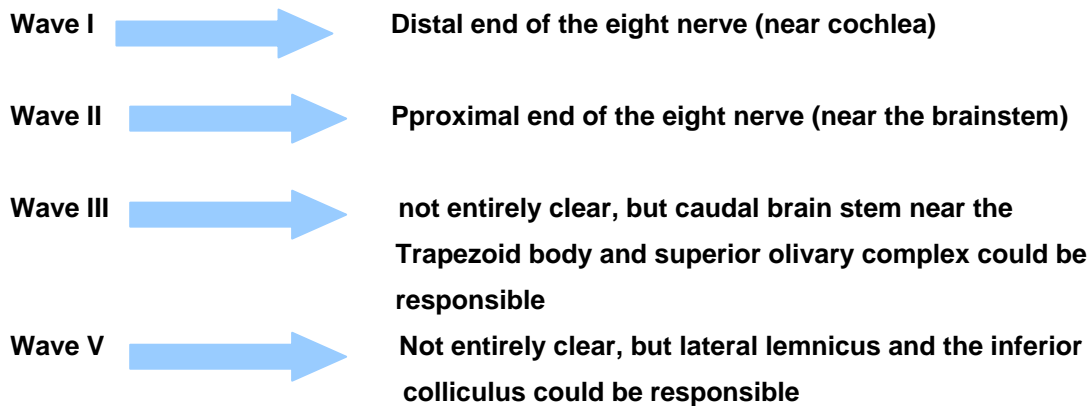
Auditory evoked responses (AER) including the auditory brainstem response (ABR), auditory steady state response (ASSR) and electrocochleography (EcochG) are objective audiometric procedures that can be employed to estimate hearing thresholds in non-collaborating populations (Aimoni, Ciorba, Bovo, Trevisi, Busi & Martini, 2010; Hall, 2007; Luts, Desloovere & Wouters, 2006). Although the latter may serve as a reliable diagnostic tool in hearing assessments, the invasiveness of this procedure may compromise its applicability in difficult to test populations (Aimoni et al., 2010). Additionally, the ASSR provides the audiologist with frequency-specific information, though this procedure is more sensitive towards a moderate-profound hearing loss which implies that a mild-moderate hearing loss may be overlooked (Hall, 2007).

Alternatively, the ABR has long been the preferred choice for auditory assessment of infant and difficult-to-test populations and the use of this procedure has been burgeoned during the past several years (Aimoni et al., 2010; Hall, 2007; JCIH, 2007; Jiang, Andrew & Wilkinson 2006; Folsom & Diefendorf, 1999; Galambos, Hicks, & Wilson, 1984).

## **2.6 The auditory brainstem response procedure in auditory assessment**

The ABR is a short latency AER that occurs in the first 10-15 milliseconds after commencement of acoustic stimuli (Hall, 2007). This response was first described by Sohmer and Feinmesser in 1967 and since then, has also been referred to as the BAEP (brainstem auditory evoked potentials) BSEP (brainstem evoked potential), BAER (brainstem auditory evoked response) or the BSER (brainstem auditory evoked response) (Hall, 2007; Jiang, Andrew & Wilkinson, 2006; Kolker, 2004; Arnold, 2000; Zafeiriou et al., 2000; Rowe 1981).

The ABR characterises the electrical activity of the cochlear part of the eighth cranial nerve as well as the neural components in the brainstem just below the inferior colliculus in response to acoustic stimulation as illustrated in Figure 2.3 (Hall, 2007; Arnold, 2000; Rowe, 1981). The electrical activity of the ABR is visually presented by series of components (I, II, III, IV, V) which, as illustrated in Figure 2.3, have various anatomical generators (Hall, 2007; Arnold, 2000; Rowe, 1981).



**Figure 2.3: Anatomic generators of the different components of the ABR**

Adapted from: Hall (2007); Arnold (2000); Rowe (1981)

The ABR is highly dependent on synchronous firing of the neural fibres (Hall, 2007; Arnold, 2000; Weber, 1994). The most optimal type of stimulus that enhances neural synchrony is an abrupt click stimulus (e.g. 0.1 milliseconds) (Hall, 2007; Luts, 2004; Arnold, 2000; Weber, 1994). The ABR recording elicited by click stimuli is usually referred to as a click-evoked ABR.

The click-evoked ABR has a dual purpose in the clinical setting. It can be used for neuro-diagnostic purposes as well as for hearing assessments (Hall, 2007; Arnold, 2000; Musiek, Borenstein, Hall & Schwaber, 1994). The robustness of the click-evoked ABR responses, that also ensures clear inter-peak and absolute latencies, contribute to the value of neuro-diagnostic assessments (Hall, 2007; Arnold, 2000). Any dysfunction or abnormality of the auditory nerve or the lower brainstem will be observed in delayed inter-peak and absolute latencies, or

ultimately, in the absence of the ABR (Hall, 2007; Arnold, 2000). Furthermore, the click-evoked ABR is a valuable procedure in objective hearing assessments of difficult-to-test populations such as neonates or children with disabilities (Hall, 2007; Arnold, 2000; Folsom & Diefendorf, 1999). Click-evoked ABR thresholds can estimate hearing thresholds within 5 dB to 10 dB of behavioural thresholds, though it is best associated with behavioural thresholds between 2 kHz to 4 kHz (Hall, 2007; Arnold, 2000; Folsom & Diefendorf, 1999; Gorga, Worthington, Reiland, Beauchaine, & Goldgar, 1985; Galambos et al., 1984).

The click stimulus encompasses energy over a broad frequency spectrum (Hall, 2007; Oates & Stapells, 1998; Gorga et al., 1993). This typically reflects activation of a wide range of the basilar membrane which correlates well with high frequency hearing in the 2 kHz to 4 kHz area (Hall, 2007; Luts et al., 2004; Arnold, 2000; Hall & Mueller, 1997; Bergman et al., 1992).

The correlation with hearing in the 2 kHz to 4 kHz area explicitly implies the limitations of this procedure, i.e. the lack of frequency-specificity and the lack of low frequency information (Hall, 2007; Marttila & Karikoski, 2005; Luts, 2004; Purdy & Abbas, 2002; Arnold, 2000; Stapells, Gravel & Martin, 1995). Without low frequency information and frequency-specific information, a hearing loss can be overestimated or underestimated (Hall, 2007). The overestimation or underestimation of a hearing loss not only affects the validity of the outcome of diagnostic audiology, but also the habilitation process. These limitations suggest the importance of the inclusion of a frequency-specific ABR procedure to complement the click-evoked ABR in diagnostic hearing assessments of difficult-to-test populations (Purdy & Abbas, 2002).

In order to provide a more frequency-specific ABR, several types of stimuli such as filtered clicks, noise stimuli and tone bursts (TB) have been employed (Hall, III, 2007; Arnold, 2000; Stapells, 2000; Gorga, 1999; Oates & Stapells, 1998). TB stimuli are the most commonly used to obtain frequency-specific information

for recording an ABR (Hood; 1998). TB stimuli are an attempt to maximize frequency specificity as well as neural synchrony: These stimuli are brief tones with a rise and fall time of a few milliseconds and a brief or no plateau duration (Hall, 2007; Arnold, 2000; Hood, 1998). These types of stimuli have narrower frequency spectra than clicks, therefore they contain energy at a specific pure tone frequency (for example 0.5 kHz) (Hall, 2007). However, the trade-off between stimulus duration and frequency specificity is well appreciated, since a TB with a very short onset may consequently produce spectral splatter (Hall, 2007; Purdy & Abbas, 2002). Blackman ramping is the most optimal method and is included in the stimulus package of most current AER systems (Hall, 2007). Blackman ramping is an alternative algorithm that refers to the appropriate shaping or windowing of the rise/fall portion of the TB and attempts to reduce the spectral splatter and ensure frequency specificity (Hall, 2007; Arnold, 2000).

Frequency-specific TB stimuli can predict reasonably accurate estimates for the pure tone audiogram in the frequency region 0.5 kHz to 4 kHz (Oates & Stapells, 1998) with threshold differences in the region of 20dB for lower frequencies and 10dB for higher frequencies (Stapells, Gravel & Martin, 1995). Thus, tone-evoked ABR can provide the essential information needed for hearing assessments, diagnosis and further management (e.g. hearing aids) of difficult-to-test populations. However, the inclusion of the click-evoked ABR remains imperative for determining the integrity and the functionality of the auditory pathway from the acoustic nerve to lower brainstem level (Hall, 2007; Oates & Stapells, 1998).

The audiologist therefore needs to employ different stimuli to attain the essential ABR information. Acquisition parameters of the ABR need to be adjusted when using click and TB stimuli respectively. Table 2.5 illustrates the different acquisition parameters for click-evoked and TB ABR recordings.

**Table 2.5: Acquisition parameters of click-evoked and TB ABR recordings**

Stimuli employed	Parameter	Suggestion	Rationale
<b>Click</b>	Filter settings	30-3000Hz, although the high pass filter can be increased to 150Hz	The click-evoked ABR correlates best with high frequency hearing; thus the low frequency energy can be cut off (e.g. 150Hz in stead of 30Hz) in order to produce a clearer recording.
	Analysis time	10 -15ms	The major components (wave I, III and V) can, at least in some cases, be observed within 5-6ms after the stimuli were presented. Analysis time of 10-15ms is recommended to encompass the major wave components in most patients, including infants.
<b>Tone burst</b>	Filter settings	30-3000Hz	The tone burst ABR is dominated by low frequency energy; thus a high pass filter of 30Hz is imperative to encompass the low frequency information.
	Analysis time	15 -20ms	The latency of wave V will increase as the frequency decreases. In order to incorporate wave V in the recording of lower tone burst ABR recordings (1kHz and 0.5kHz), a longer analysis time is needed.

Adapted from: Hall (2007)

## **2.7 The auditory brainstem response as assessment method in the cerebral palsy population**

The objectivity and frequency-specificity (provided TB stimuli are used) of the ABR make it an ideal procedure for auditory assessments of difficult-to-test populations such as individuals with CP (Hall, 2007; Arnold, 2000; Sininger 1993; Galambos et al., 1985). Table 2.6 summarizes a list of studies in which the ABR was conducted in a population with multiple disabilities, including CP.

Research on ABR assessments within the CP population is dominated by studies that employed click stimuli only, as illustrated in Table 2.6 (Romero et al., 2008; Sano et al., 2005; Kolker, 2004; Topolska et al., 2002; Zafeiriou et al., 2000; Sheykholeslami & Kaga, 1999; Benham-Dunster & Dunster, 1985; Stein et al., 1981). As click stimuli correlate best with hearing in the 2 kHz to 4 kHz region, the majority of the research provides information regarding hearing in these frequencies only (Hall, 2007; Gorga et al., 1985). This highlights the lack of low frequency and frequency-specific ABR information for the CP population. This information is crucial for the intervention process; especially in the CP population where information over the entire frequency spectrum is rarely obtainable without objective procedures.

The objectivity of the ABR favoured this procedure in various research projects involving the CP population (Sano et al., 2005; Kolker, 2004; Zafeiriou et al., 2000; Sheykholeslami & Kaga, 1999). Although it is an objective procedure, the audiologist still needs to take some considerations into account during assessment of this population as it may influence the outcome of the results and ultimately, the diagnosis.

One of the considerations that needs to be taken into account when recording an ABR in the CP population is the fact that children with CP present with an immature central nervous system (CNS) (Donnelly et al., 2007; Workinger, 2005; Cogher et al., 2002; Hutton & Pharoah, 2002). Immaturity of the CNS causes prolonged latencies (inter-peak and absolute latencies) of the ABR and these must be accounted for when utilizing the ABR in this population (Hall, 2007; Jiang & Wilkinson, 2005).



**Table 2.6: Summary of previous studies in which the ABR procedure was conducted in a population with multiple disabilities**

Author	Research aim
Romero, Mendez, Tello & Torner (2008)	To characterize the ABR differences between children with perinatal encephalopathy and healthy children
Sano, Kaga, Kitazumi & Kodama (2005)	To identify the location of causing hearing loss in patients with CP due to asphyxia and hyperbilirubinemia
Kolker (2004)	To determine hearing function by means of auditory evoked potentials (ABR and cortical potentials) in the population with spastic CP
Topolska, Hassmann-Poznańska, Sołowiej (2002) **	To assess hearing function in children with infantile CP
Zafeiriou, Andreou & Karasavidou (2000)	To determine the utility of the ABR in the population with spastic CP and determine inter wave latencies of the ABR in this population
Sheykholeslami & Kaga (1999)	To localize the pathophysiology of hearing loss in subjects with hyperbilirubinemia by utilizing OAE and ABR measurements as well as behavioural audiometric techniques
Benham-Dunster & Dunster, (1985)	To compare behavioural, acoustic reflexes and ABR procedures in developmentally delayed population
Stein, Ozdamar & Schnabel (1981)	To determine the utility of the ABR with multi-handicapped and suspected deaf-blind children
<b>Current study</b>	<b>To determine the clinical utility of the VS ABR system in children with CP</b>

\*\* Research report was only available in Polish, thus information was obtained from the English abstract only

Within the CP population, it appears that latency values vary (Kolker, 2004; Zafeiriou et al., 2000; Sheykholeslami & Kaga, 1999). Prolonged inter-peak latencies during ABR recordings of subjects with spastic CP were reported by

Kolker (2004) and Zafeiriou, Andreou & Karasavidou (2000). However, normal inter-peak latencies were also reported (Zafeiriou et al., 2000; Sheykholeslami & Kaga, 1999). The discrepancy in the latency values may be attributed to the range of disorders and their severity severities in the CP population and correlates with the heterogeneity of this population.

The clinical audiologist needs to consider the intactness of the CNS because important ABR components may appear at later time intervals where the compromised CNS is compromised. Thus, by the implementation of, for example, an increased analysis time e.g. 20ms instead of 15ms, all the ABR components may be visualized. All ABR components may, longer analysis time notwithstanding, not always be visualized – like in some CP cases where ANSD is present (Hall, 2007). Alongside the presence of a cochlear microphonic response, ANSD will produce either absent or abnormal and poorly defined ABR recordings at maximum intensity, i.e. 95dB nHL (Rance, Beer, Cone-Wesson, Shepherd, Dowell, King, Rickards, & Clark, 1999).

Absent or abnormal ABR findings were recorded in some studies within the CP population (Sano et al., 2005; Kolker, 2004; Sheykholeslami & Kaga, 1999). The majority of the CP population who presented with abnormal or absent ABR recordings had a history of hyperbilirubinemia (Sano et al., 2005; Sheykholeslami & Kaga, 1999). Since hyperbilirubinemia is a high risk factor for ANSD it may be speculated that the ABR findings were abnormal or absent due to the presence of ANSD (Hall, 2007; Shapiro, 2003). Unfortunately, ANSD as a topic has not been documented in any of the previous research reports (Sano, Kaga, Kitazumi & Kodama, 2005; Kolker, 2004; Sheykholeslami & Kaga, 1999). It remains an important issue, however, to consider in CP cases where ABR recordings are strange or abnormal.

Irregular ABR recordings in the CP population may also be attributed to an inadequate signal to noise ratio (SNR). A poor SNR originates from noise levels

exceeding the amplitude of the incoming stimuli (Sanchez & Ganz, 2006; Kurtz & Steinman, 2005). Any noise produced internally e.g. movements of the body including the eyes, head or jaw will result in myogenic potentials that increase the noise levels (Hall, 2007; Sanchez & Ganz, 2006). Within the CP population, uncontrollable or involuntary movements may be responsible for excessive myogenic potentials that decrease the SNR and ultimately contaminate the ABR recording.

Previous research rarely mentions the effect of uncontrollable or involuntary movements or the presence of ANSD on ABR recordings (Sano et al., 2005; Kolker, 2004; Zafeiriou et al., 2000; Sheykholeslami & Kaga, 1999). It is imperative that both factors be considered since these factors can lead to invalid ABR recordings and ultimately to erroneous diagnosis. For example, when suspecting the presence of ANSD, the polarity of the stimulus (i.e. rarefaction and condensation) needs to be changed (Hall, 2007). In addition, the effects of sporadic muscular movements need to be considered as well, since it may contaminate the SNR which in turn may affect accurate identification of ABR wave components. In an attempt to improve the SNR various technical parameters of the conventional ABR system may be modified (Hall, 2007; Kurtz & Steinman, 2005).

### **2.7.1 Improving the signal-to-noise ratio in the conventional auditory brainstem response system**

Modifications of the technical parameters of the conventional ABR system include alterations to the amplification scale, filtering settings, the amount of signal averaging and artifact rejection that are used by the ABR system (Hall, 2007; Sanchez & Ganz, 2006).

The theoretical principle of each technique used by the conventional ABR system is presented in Table 2.7. Basically, the main objective of all the techniques is to present a well-defined ABR recording. More specifically, in order to record a

distinct ABR, the aim of filtering, signal averaging and artifact rejection is to improve the SNR, while amplification focuses on presenting improved ABR amplitude.

The amplitude of the evoked response generated by the cochlea, auditory nerve and brainstem is minute (for wave V of the ABR approximately only 0.5 microvolt); amplification is a critical component (Hall, 2007). However, amplification is the first process in conventional ABR technology which implies that additional responses such as myogenic potentials or electrical interferences may also be generated and, as a result, also be amplified. When myogenic potentials or electrical interferences are extensive, the amplitude of these background noises (e.g. 100 microvolt) may exceed that of the ABR, contaminating the SNR.

In order to reduce the amplitude of unwanted electrical noise or myogenic potentials but preserve the actual ABR, band-pass filter settings may selectively be modified (Hall, 2007). The selected settings of the high pass/low cut and low pass/high cut filters will determine the electrical activity that will pass through the filters for the averaging process (Hall, 2007; Arnold, 2000). A high pass/low cut filter setting of 30 Hz and low pass/high cut filter setting of 1500 Hz (or 3000 Hz) is generally effective: a setting of 30 Hz will filter out normal EEG as well as electrical energy below 30 Hz, while settings of 1500 Hz or 3000 Hz will reduce interferences during ABR measurement due to activity in the higher frequency range (Hall, 2007).



**Table 2.7: Principles and limitations of conventional ABR technology**

Technique	Theoretical principle	Limitation
<b>Amplification</b>	Because the ABR is such a minute response, it has to be amplified substantially (i.e. up to 100,000 times) before it can be processed by a signal averaging process and displayed on a computer screen (Hall, 2007)	Myogenic, magnetic and electric potentials may share a portion of the ABR frequency spectrum (30Hz-100Hz) (Hall, 2007). Conventional ABR technology amplifies the broad signal, including these potentials, which may result in a less identifiable ABR recording.
<b>Filtering</b>	The implementation of filters attempts to eliminate unwanted electrical activity (the noise) of the desired electrical activity (the actual response) (Hall, 2007: 63)	Minimal improvement of the SNR as the amplified broad signal – the ABR and the myogenic potentials pass through the filters. Furthermore, the frequency spectrum of the myogenic potentials (50-500Hz) often overlaps with the frequency spectrum of the ABR (30-3000Hz) (Hall, 2007; Sanchez & Gans, 2006).
<b>Signal averaging</b>	The time (signal averaging) needed to record a detectable response is depends on the size of the signal as well as the amount of myogenic or electric potentials (noise) within the recording (Hall, 2007: 63). Thus; signal averaging attempts to reduce noise by the square root of the number of sweeps in an averaged response (Sanchez & Gans, 2006).	Less sweeps are required to elicit an adequate SNR if minimal myogenic potentials are present suggesting a shorter recording time. On the contrary, the more myogenic potentials detected by the electrodes, the more sweeps are needed to obtain an ABR recording. This suggests that an ABR recording may take very long when muscle artifacts are in excess.
<b>Artifact rejection</b>	An artifact (in AER recording) can be defined as electrical activity that is not part of the AER and thus should be excluded during the analysis (Hall, 2007). Artifact rejection is an approach used during AER recording to minimize the effect of the artifacts on the recording. This approach evaluates the amplitude of the incoming noise from the electrodes for each sweep and rejects the sweep from the averaging process when the noise exceeds a predetermined microvolt level (Sanchez & Gans, 2006:154).	The inability of this approach to make progress with the averaging process due to continuous artifact rejection can be responsible for a lengthy ABR recording time. Furthermore, the obvious contamination of a waveform that is being averaged with artifact despite the use of this approach is another limitation (Hall, 2007; Sanchez & Gans, 2006).

The filtering process will, however, not obscure all the effects of unwanted background noise (Hall, 2007; Sokolov, Kurtz, Sokolova, Steinman, Tedesco & Broome, 2007). In an attempt to improve the SNR even further, thereby improving the visibility of the recorded ABR, the signal averaging technique is applied (Sanchez & Gans, 2006).

The signal averaging process has been described as the heart of the conventional evoked response system (Hall, 2007). The technique is based on the assumption that presenting repetitive acoustic stimuli (sweeps) results in a constant pattern in auditory brain activity within a certain time (Hall, 2007; Sanchez & Gans, 2006; Arnold, 2000; Sininger, 1993). However, the time needed to record a detectable ABR depends largely on the amount of background interferences such as myogenic potentials during the recording (Hall, 2007: 63).

In the presence of minimal myogenic potentials the ABR may be recorded within a short period of time as fewer sweeps are required during the signal averaging process. On the other hand, the signal averaging process will take longer when myogenic potentials are in excess, when more sweeps will be presented in an attempt to improve the SNR. However, in some instances where the child displays excessive muscular movements on a sporadic basis, the utilization of more sweeps, i.e. more signal averaging, may not improve the SNR sufficiently.

In an attempt to record a detectable ABR in the midst of sporadic muscular movements, artifact rejection is often incorporated in conventional ABR systems (Sanchez & Gans, 2006). Although there are other techniques of artifact removal available that focuses specifically on offline averaging e.g. Bayesian weighted average and artifact rejection equal noise average, the majority of clinical systems employs the artifact rejection technique (Sanchez & Gans, 2006).

Artifact rejection evaluates the amplitude of the incoming noise from the electrodes for the individual sweeps and rejects a sweep if the incoming noise exceeds predetermined microvolt levels, i.e. rejection criteria (Sanchez & Gans, 2006). Although rejection criteria may often range between 10 microvolt and 20 microvolt for example, a more conservative criteria level may be selected during an ABR recording which is characterized by excessive myogenic potentials (Sanchez & Gans, 2006).

Some populations, e.g. the population with CP, may display excessive myogenic potentials due to involuntary muscular movements. The extensiveness of these muscular movements may have a negative impact on amplification, filtering, signal averaging as well as artifact rejection techniques of the conventional ABR system.

### **2.7.2 Cerebral palsy and conventional auditory brainstem response technology**

The presence of involuntary muscular movements typically displayed in CP may hinder the feasibility of conventional ABR recording. The feasibility of the ABR may be compromised as the modified settings of the conventional techniques may not sufficiently capture the extensiveness of the muscular movements, which evidently may result in an inadequate SNR.

The SNR may be inadequate in the presence of excessive muscular movements since myogenic potentials, which are generated by muscular movements, may share a portion of the ABR frequency spectrum (frequency spectrum of myogenic potentials: 50 Hz to 500 Hz; frequency spectrum of ABR: 30 Hz to 3000 Hz) (Hall, 2007). The fact that there is an overlap in the frequency spectrum suggests that the SNR might already have been contaminated during the amplification process since a broad signal, which include the ABR signal as well as myogenic potentials, is amplified in conventional ABR technology (Hall, 2007; Kurtz, Sokolova, Steinman, Tedesco & Broome, 2007). Furthermore, the fact

that the overlap in the frequency spectrum tends to be specifically in the low frequencies implies that the low cut filter setting may need to be set to the maximum in an attempt to filter out the adverse effects of myogenic potentials on the SNR.

However, when implementing a higher low cut filter setting, the danger arises that portions of the ABR may be eliminated, which naturally may result in an inaccurate ABR waveform (Hall, 2007). ABR waveforms elicited by both click and TB stimuli may be affected, though TB ABR recordings are particularly vulnerable to severe filtering. TB stimuli depend on low frequency energy, thus the utilization of a high low pass band filter, e.g. 100 Hz or 150 Hz suggests that essential information between 30 Hz and 100 Hz/150 Hz may be eliminated.

Clearly, the feasibility of the conventional ABR in the CP population may be affected by inadequate functioning of the amplification and filtering techniques due to the influence of myogenic potentials. The presence of myogenic potentials may, however, offer unique challenges to the signal averaging and artifact rejection techniques.

Excessive myogenic potentials may have a strenuous effect on the signal averaging and artifact rejection techniques which may ultimately affect the feasibility of the recording (Sanchez & Gans, 2006). The ABR signal may be impossible to detect when contaminated by undesired potentials, even with the inclusion of more sweeps, i.e. more signal averaging. In addition, the utilization of artifact rejection can have detrimental effects on the morphology of the ABR (Sanchez & Gans, 2006).

Together with the possibility of the ABR being compromised, the period in which the ABR is recorded may also increase. When myogenic potentials are in excess, more sweeps are required. In addition, the inability of the artifact rejection technique to make progress with the averaging process due to



continuous artifacts being rejected may also lengthen ABR recording time. The recording time of a hearing test, including the ABR, remains crucial, especially in difficult-to-test populations such as CP and as much information as possible must be obtained in the shortest time available (Gorga et al., 2006; Bachmann & Hall, 2001). Thus, the ABR needs to be conducted efficiently and quickly.

Limited research is available regarding the recording time and efficiency of the ABR procedure with specific reference to the CP population (Sano et al., 2005; Kolker, 2004; Zafeiriou, Andreou & Karasavidou, 2000; Sheykholeslami & Kaga, 1999; Benham-Dunster & Dunster, 1985; Stein et al., 1981). Despite the limited research, it is apparent that the extensiveness of the muscular movements may have a detrimental effect on conventional ABR techniques and may affect both the feasibility and the recording time negatively. It is apparent that modifications to the acquisition parameters of the conventional ABR system alone may not adequately improve the SNR due to the effects of involuntary muscular movements. In an attempt to reduce the effects of the muscular movements, e.g. by enhancing the restfulness of the child, certain patient management techniques can be implemented (Hall, 2007; Surya, Harkera, Begentb, & Chongc, 2005).

### **2.7.3 Improving the signal-to-noise ratio by implementing patient management techniques**

The restfulness of the child may enhance low muscular activity which can contribute to effective recording of the ABR. The audiologist may implement a few patient management techniques to enhance the required restfulness. These patient management techniques include natural sleep, sleep deprivation or the use of melatonin, sedation or general anaesthesia (Hall, 2007; Surya et al., 2005).

Although these patient management techniques may improve the quiet state of the child and the ABR recording, there are various disadvantages which can be summarized as follows:

- ❖ Time insufficiency
- ❖ Expenditure
- ❖ Health risks

Natural sleep and sleep deprivation are both cost-effective techniques and, compared to sedation or general anesthesia imposes the least health risks. However, these techniques might be impractical as children, especially older children, may become irritable and take a long time before falling asleep. Additionally, muscle artifacts are often still present in natural sleep in which case the signal to noise ratio of the ABR recording will not be improved (Surya et al., 2005). If natural sleep or sleep deprivation is ineffective, the audiologist may be forced to make use of sedation or any form of general anesthesia.

However, several researchers have reported that sedation or general anaesthesia may impose multiple health risks such as sleep apnoea or upper airway obstruction in severely handicapped children such as those with CP (Schmidt, Krief, Deuster, Matulat & Zehnoff-Dinnesen, 2007; Wasemer & Whitehouse, 2002; Elwood, Hansen & Seeley, 2001). According to Elwood et al. (2001) severely handicapped children are especially at risk for upper airway obstruction as this population (including children with CP) display a narrower antero-posterior diameter of the airway at the level of the soft palate as opposed to children without any developmental delay.

A light sedative in the form of melatonin has been employed in children with developmental delays and severely handicapped children during procedures such as CT, PET, MRI or the ABR procedure (Schmidt, Krief, Deuster, Matulat & Zehnoff-Dinnesen, 2007; Surya et al., 2005). This sleeping agent has been proven to enhance sleep in children during these medical procedures (Schmidt et al., 2007). However, melatonin might be more effective in younger children than in older ones and side effects such as sleep apnea may still occur in some children. Thus, careful observation of the airway during sedation or general anaesthesia is essential in ensuring safe management (Elwood et al., 2001).

Safe management of general anaesthesia is an expensive process in the hospital setting. It involves the use of highly specialized equipment and trained personnel (Schmidt et al., 2007). Public health care in South Africa is already challenged with problems such as poverty and infectious diseases e.g. HIV/AIDS (Theunissen & Swanepoel, 2008), thus limiting the financial expenditure on specialized services such as general anaesthesia for an ABR for a non-life-threatening condition such as a hearing loss. Although the use of sedation may be viewed as more cost-effective than general anaesthesia, especially in the public health care system of South Africa, it still requires constant supervision of the child. For difficult-to-test populations such as CP the increased risk for apnoea still remains (Schmidt et al., 2007; Rowe, 1981).

Not only does sedation and general anaesthesia increase the risk for airway obstruction (especially in difficult-to-test populations), but it may also not be cost-effective for the public health care systems of developing countries such as South Africa. Yet, without sedating or anaesthetizing an uncooperative child, the ABR may not be reliable due to the negative effects of excessive muscular movements on the recording. Therefore, the usefulness of the conventional ABR instrument may be seriously limited, especially in populations where sedation or general anaesthesia can not be administered. This also suggests that conventional ABR technology may limit its applicability for the variety of patients seen in clinical practice. From the above it becomes clear that audiologists are in need of ABR technology that is less sensitive for the effects of excessive muscular movements.

#### **2.7.4 Novel technology for improving ABR signal-to-noise ratio**

Recently an ABR system, the Vivosonic Integrity™ (VS), has become available (Hall, 2007). The VS was first introduced in 2006 and has since been used in various clinical facilities across the US (Sokolov et al., 2007). What makes this system particularly appealing to the audiologist is the potential that an ABR may

be reliably recorded within the presence of muscular activity (Hall, 2007; Kurtz & Steinman, 2005). This potential suggests the prospect of eliminating or reducing the number of cases requiring sedation or general anaesthesia for ABR assessments. This supposed advantage also holds significant promise for assessing auditory functioning in children with CP.

The supposed benefit of the VS system lays with the introduction of three novel features namely the pre-amplification of the evoked response, Kalman-weighted averaging and wireless/blue-tooth recording (Hall, 2007). Each feature endeavours to address the challenges often found in conventional ABR recordings. These features as well as the underlying principles and the expected advantage in ABR recording is presented in Table 2.8. The inclusion of wireless recording poses a definite advantage over conventional ABR systems. While the set-up of the conventional ABR system seriously jeopardizes the pureness of the ABR signal because of electrically conducted noises that may stem from the power line and the computer, wireless recording eliminates such contamination of the signal (Hall, 2007). Wireless recording removes the electric path (i.e. wires) between the computer and the amplifier, eliminating electrically conducted interferences (Hall, 2007).

The elimination of electrical interferences will, however, not ensure a well-defined ABR recording in the presence of myogenic potentials. In order to manage the effects of the myogenic potentials, remaining features (i.e. alternative filtering and Kalman averaging) is incorporated. The alternative filtering, also referred to as pre-amplification, accomplished through the Amplitrode™. The Amplitrode™ is a miniature, on-site AER amplifier fitted directly on the ABR electrode (Hall, 2007). The significance of the location of the amplifier lies in the fact that the signal is filtered prior to amplification (Hall, 2007). This alternative filtering arrangement suggests that the amplified signal may be less contaminated by myogenic potentials. This feature differs from conventional ABR technology where amplification occurs prior the filtering process.

**Table 2.8: Principles and supposed advantages of the VS ABR system**

Technique	Underlying principle	Supposed advantage
<b>Alternative Filtering/ Pre-amplification</b>	The input signal is filtered prior amplification by means of the Amplitrode, the on-site AER amplifier (Hall, 2007)	The amplified response is less contaminated by unwanted low frequency myogenic potentials such as general muscular activity, EOG, ECG and EEG (Hall, 2007).
<b>Kalman Averaging</b>	Each sweep is individually considered during the averaging process: more weight (value) is awarded to signals with less noise, and less weight (value) is awarded to contaminated/noisier signals (Steinman & Kurtz, 2005)	This technique promises to reduce the effects of sporadic noise during ABR recording (Sokolov et al., 2007; Steinman & Kurtz, 2005)
<b>Wireless/Blue tooth recording</b>	Communication between the interface module (VivoLink) and the computer is performed wirelessly. Wireless communication is possible as long as the computer and the VivoLink are within a 10m distance of each other.	This feature promises to eliminate the introduction of electrically conducted noises from the computer as well as the power line (Hall, 2007:90).

Also different to ABR technology is the incorporation of Kalman averaging. Kalman averaging may allow an improved SNR during significant muscular activity (Hall, 2007). It constitutes a weighted averaging algorithm where each sweep is individually considered in order to obtain an ABR with minimum probability of error, regardless of the patient's muscular activity (Hall, 2007; Kurtz & Steinman, 2005). This averaging technique aims at estimating the error in each sweep based on the measurement variance and continuously updates this estimate to produce an estimate of the ABR signal (Hall, 2007). As the likelihood of error in the amplitude estimate at each latency point is minimized in the predicted ABR, the effects of sporadic muscular movements on the ABR may be reduced (Hall, 2007; Kurtz & Steinman, 2005). This suggests that the ABR may be recorded reliably and accurately, even in the presence of significant muscular movements (Hall, 2007; Kurtz & Steinman, 2005).

The information above suggests that the new technology introduced by the VS ABR system may be less affected by the influence of excessive muscular movements. This may enhance ABR assessments in the CP population since involuntary muscular movements are common in this population (Workinger, 2005; Mechem, 2002; Stanton, 1992).

## **2.8 Conclusion**

CP is a diverse condition which may involve various disabilities including hearing loss (Stanton, 1992). A hearing loss in a CP child needs to be identified as early as possible for efficacious intervention to be realized. Identifying an additional hearing loss in members of the CP population could be challenging when relying on conventional audiometry procedures such as behavioural audiometry and OAE measurements (Sano et al., 2005; Topolska et al., 2002; Driscoll et al., 2000, Venter, 2000). For this reason the audiologist relies on the ABR to provide an estimate of hearing sensitivity (Hall, 2007). Traditionally, ABR assessment in difficult-to-test populations such as the CP population was challenged as the acquisition parameters could not fully compensate for the presence of involuntary and irregular body movements. Although these sporadic movements can be manipulated by sedation or general anaesthesia, both of these processes are not cost-effective and impose the risk of airway obstruction, especially in severely handicapped children (Schmidt et al., 2007; Johnson et al., 2002). The inclusion of the VS ABR system's novel features may reduce the need for sedation or general anaesthesia which could be especially beneficial for ABR assessments of severely handicapped children (Kurtz & Steinman, 2005). The incorporation of pre-amplification, Bluetooth recording and Kalman averaging holds the promise of a well-defined ABR recording, even in the presence of excessive body movements.

## **2.9 Summary**

The possibility of obtaining distinctive ABR recordings with the VS system, even in the presence of excessive body movements, suggests that the utilization of

sedation or general anaesthesia may become redundant for VS ABR assessments. This not only favours the applicability of ABR assessments in public health care hospitals of South Africa, but also the assessment outcomes in the difficult-to-test CP population, since a hearing loss may be detected much earlier than previously. If early identification of the hearing loss is followed by appropriate intervention, e.g. hearing aids and auditory training, the child with CP may be integrated in the community despite his/her physical and cognitive constraints.

## Chapter 3

# METHODOLOGY

*The aim of this chapter is to describe the methodological approach that was implemented during the empirical research component of this study.*

### 3.1 Introduction

Research can be described as the process of investigating scientific questions (Hedge, 2003:24). The motivation for this research and the research question underlying this project was described in the preceding chapter. In order to practically investigate the research question, the process was dependent on a methodological foundation (Maxwell & Satake, 1997).

The research methodology outlined in this chapter describes the process that was followed in order to determine the clinical usefulness of the Vivosonic Integrity Auditory Brainstem Response (VS ABR) system in the auditory assessment of children with cerebral palsy (CP).

### 3.2 Aims of the research

The following aims have been specified for this study.

#### 3.2.1 Main aim

The main aim of this project was to evaluate the clinical utility of the Vivosonic Integrity ABR system in children with cerebral palsy.

#### 3.2.2 Sub-aims

The following sub-aims were formulated to realize the main aim:



### **Sub-aim 1**

To describe the feasibility and characteristics of an audiometric test battery for assessing auditory functioning in children with cerebral palsy.

### **Sub-aim 2**

To compare the VS ABR system with a conventional ABR, in terms of:

- ❖ Feasibility using click and 0.5 kHz tone burst (TB) stimuli;
- ❖ Electrophysiological thresholds using click and 0.5 kHz TB stimuli;
- ❖ Threshold correspondence with behavioural PT thresholds;
- ❖ Recording time using click and 0.5 kHz TB stimuli.

## **3.3 Research design**

A cross-sectional, within-subject comparison design implementing a quantitative research approach was selected for this study (Leedy & Ormord, 2005; Maxwell & Satake, 1997; Johnston & Pennypacker, 1993). The study was cross-sectional in that all the data for each subject was collected at a specific time (Maxwell & Satake, 1997). The experimental part of this study was represented by the within-subject control condition where two ABR systems, a conventional ABR system and the VS ABR system, were simultaneously conducted in each subject. The conventional ABR system served as the controlled condition whilst the VS ABR system served as the experimental condition. This unique setup was important in the research as equivalent test conditions in terms of EEG and environmental conditions had to be ensured for both ABR systems. All the subjects were exposed to both the control and the experimental conditions; thus within-subject comparisons were the outcome of this research.

The conclusions and implications of any experimental design are dependent on the dependent (measured) and independent (manipulated) variables as well as on the experimental setting (Johnston & Pennypacker, 1993). This study investigated the usefulness of the VS ABR system when assessing auditory functioning in children with CP. The *manipulated variables* for this study were

the procedure employed to determine hearing thresholds (behavioural PT audiometry) and the procedures employed to estimate hearing thresholds (a conventional ABR system and the VS ABR system). The *dependent variables* were the thresholds obtained with different stimuli (click and 0.5 kHz) with the VS and conventional ABR systems. The PT thresholds at 0.5 kHz, 1 kHz, 2 kHz and 4 kHz are also considered dependent variables as these specific frequencies were manipulated by the researcher. Behavioural PT thresholds obtained at these frequencies served as the gold standard (reference hearing threshold) against which the thresholds of the VS and conventional ABR systems were compared.

### **3.4 Ethical considerations**

Different auditory evoked potential equipment was used by researcher; thus it is important to mention that the researcher had no relationship to either Vivosonic or Bio Logic.

The study was approved by the Ethics Committee of the University of Pretoria (Appendix A) as well as the Gauteng Department of Education (Appendix B). A meeting was also scheduled with the principal of the Pretoria School for Children with Cerebral Palsy as well as the head of the Speech therapy and Audiology department of the school. Prior to the meeting mentioned above, the principal of the school was provided with a letter requesting informed consent in which the details of the research were also explained (Appendix C).

The fundamental principle of ethical research is to preserve and to protect the rights and welfare of all the subjects involved in a research project (Jenkins, Price & Straker, 2003). Hence, the following ethical considerations were taken into account (Maxwell & Satake, 1997):

### **3.4.1 Respect of privacy of research subjects**

To respect the privacy of the subject is a fundamental ethical principle (Leedy & Ormrod, 2005). Confidentiality of the subjects was ensured by not using the individuals' names on any data documentation during the research project (Strydom, 1998). A specific code was allocated for each subject for data processing purposes. This was clearly explained in the letter requesting informed consent which was mailed to the parents of the subjects (Appendix D).

### **3.4.2 Informed consent**

According to Leedy & Ormrod (2005) and Strydom (1998) obtaining informed consent entails the following components:

- ❖ Providing the subjects with adequate information regarding the research;
- ❖ Emphasizing voluntary participation;
- ❖ Informing subjects that they could withdraw at any time during the research

Subsequently, the researcher obtained letters granting informed consent from each subject's parents (included as Appendix D). This letter was signed by the parents after they have read the aims, procedures and the possible benefits of the study. This letter ensured confidentiality and voluntary participation as well as each subject's right to withdraw at any time during the research (Kidder & Judd, 1986).

Additionally, verbal consent was also obtained from each subject prior the auditory assessments. As it was the responsibility of the researcher to convey the information in such a way that it was understandable to the each subject, the entire procedure was explained to the subject in the presence of either the teacher or the speech therapist of the school (Iacono & Murray, 2003). Voluntary participation was ensured and it was emphasized that the subject had the right to withdraw at any time during the research (Appendix E).

### **3.4.3 Beneficence and non-maleficance**

When conducting the various tests, acoustic stimuli were presented at a comfortable listening level and lower intensity levels, therefore not causing any discomfort to the subject. The letter requesting informed consent stated the duration of the sessions and also that the subject were actively involved during only one test (pure tone audiometry). Any abnormality that was noted during any auditory assessment was communicated to the speech therapist and the teacher for further management, thereby rendering a service to the parents and subjects.

The research project posed no medical risks to the subjects (no sedation was used). The information that was gathered provided useful data for future hearing assessments in individuals with CP.

### **3.5 Research sample**

15 Subjects were selected from the Pretoria School for Children with Cerebral Palsy. Although the sample size was small, comprehensive audiological assessments were conducted in each subject. Table 3.1 presents the criteria that subjects had to comply with to participate in the research project. The heterogeneity of the research sample might be seen as confounding the quality of the interpretation of the especially the ABR data; however data were collected during school hours which limited the availability of possible subjects.

#### **3.5.1 Selection criteria and procedures**

A non-probability purposive sampling procedure was used to select subjects for the research group (Hedge, 2003; Maxwell & Satake, 1997). According to Hedge (2003:96) purposive sampling can be viewed as *'a method of handpicking individuals because they have special characteristics that are necessary for the study'*. Although purposive sampling typically limits generality, this method is specific and useful in clinical research (Hedge, 2003).

Table 3.1 presents the selection criteria for the research sample of the study. The following procedures were followed for selecting the research sample:

- ❖ The aim of this research was discussed during a scheduled meeting with the head of the targeted school and the head of the Speech Therapy and Audiology department of the school.
- ❖ The researcher discussed the criteria for subject with designated teachers and letters requesting informed consent were handed to them.
- ❖ Based upon the age criteria (between 12 and 18 years), teachers distributed the letters.

**Table 3.1: Selection criteria for the research sample**

Criteria	Rationale
<b>Cerebral palsy</b>	Children diagnosed with CP as defined by the medical records of the Pretoria School for Children with Cerebral Palsy were selected for this study
<b>Age</b>	Subjects between the ages of 12 and 18 years were selected for this research. Less modification of standard audiometric procedures is needed as children get older (Northern & Downs, 1991). For this reason conventional pure tone audiometry is more likely to be used in older children than the modified play audiometry.
<b>Normal middle ear functioning</b>	Middle ear pathology influences the accuracy of the pure tone thresholds as well as the latency and morphology of the ABR recording (Hall & Mueller, 1997); Therefore normal middle ear functioning is a requirement. According to Worthington & Peters (1984) peripheral effects, such as a conductive component, should be ruled out before an abnormal ABR can be interpreted.

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- ❖ Because of certain time constraints, a cut off date of 2 weeks for returning the informed consent letters was stipulated.
  - ❖ The children from whom letters granting informed consent were received were scheduled for the hearing tests.

- ❖ Specific dates were scheduled with the Speech Therapy and Audiology department at the school to conduct the testing at that venue.
- ❖ Otoscopy and tympanometry was conducted and if not complying with the set criteria for participation, the child was eliminated from the study.
- ❖ If the hearing test results were compliant with the selection criteria, the researcher proceeded with the behavioural PT audiometry and DPOAE measurements.

### **3.5.2 Description of the research sample**

The relevant biographic details of each subject are illustrated in Table 3.2. The subjects' ages were documented as the age at the time of the study. Although the causes of CP were unknown in the majority of the subjects, it was apparent through the school medical records that most acquired the condition during or directly after birth. Only one subject (subject 7) was diagnosed with CP after a motor vehicle accident at the age of three years. All the subjects were diagnosed according to a physiological and topographical classification protocol by a professional team (including a neurologist, physiotherapist, occupational therapist and speech-language therapist) at the time of their intake by the school.

## **3.6 Material and apparatus**

The material and apparatus used in this research can be divided into apparatus used for the selection of the research sample and that used during the data collection. Both of these categories are discussed in the following section.

### **3.6.1 Material and apparatus for subject selection**

The following material and apparatus were used for the selection of the research sample:

#### **3.6.1.1 Otoscopic examination**

Otoscopy examination of the external meatus and the tympanic membrane was performed with a Heine Mini 2000 Otoscope. A visible light reflex is most often indicative of a healthy tympanic membrane (Hall & Chandler, 1994).

**Table 3.2: Description of the research sample**

Subject	Age	Gender	Type of CP	Language of education	Related auditory problems (previously determined)	Other disabilities
1	17	Male	Spastic diplegia	Afrikaans	None	Language learning problems
2	15	Female	Spastic diplegia	Afrikaans	None	Language learning problems
3	15	Female	Microcephaly	Afrikaans	None	Language learning problems
4	15	Male	Spastic quadriplegia	Afrikaans	None	Non-ambulatory, limited speech repertoire
5	16	Female	Athetosis	Afrikaans	Bilateral high frequency hearing loss	Vision problems; limited speech repertoire
6	14	Female	Right hemiplegia	Afrikaans	None	Language learning problems
7	16	Female	Right hemiplegia	Afrikaans	None	Mental Retardation
8	15	Female	Athetosis	Afrikaans	None	Dysarthria; Language learning problems
9	16	Male	Spastic Diplegia	Afrikaans	None	Language learning problems
10	16	Male	Right hemiplegia	Afrikaans	None	Language learning problems
11	17	Male	Spastic triplegia	English	None	Language learning problems
12	13	Male	Spastic triplegia	English	None	Limited speech repertoire; Language learning problems
13	17	Male	Right hemiplegia	English	None	Language learning problems



14	17	Male	Athetosis	Afrikaans	None	Language learning problems
15	15	Male	Athetosis	Afrikaans	Hearing loss was suspected; though not confirmed	Language learning problems; limited speech repertoire

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### 3.6.1.2 Tympanometry

Tympanometric evaluation of the middle ear was performed with a GSI 38 Auto Tymp Middle Ear Analyzer. A type A tympanogram with normative values as reflected in Table 3.3 was indicative of normal middle ear functioning.

**Table 3.3: Normative tympanometric values**

Components of tympanometric measurements	Normative values
Ear canal volume	0.5 -1.5 ml
Compliance	0.3 -1.6 cc
Middle ear pressure	-100 - +100 daPa (adults) -150 - + 150 daPa (children)

Adapted from: Stach (1998); Hall & Mueller (1997)

### 3.6.1.3 Case history

Information regarding the subject's date of birth as well as the diagnosis of the CP condition was obtained from the medical files of the school.

## 3.6.2 Material and apparatus used for data collection

The following material and apparatus were used during data collection. The specific protocol that was employed for each auditory procedure is also included in this section.

### 3.6.2.1 Ipsilateral acoustic reflexes

Ipsilateral acoustic reflex thresholds were obtained using a GSI 38 Auto Tymp Middle Ear Analyzer. Ipsilateral acoustic reflexes were measured at 0.5 kHz, 1 kHz and 2 kHz with pulsed pure tones. These frequencies were selected in order to describe the auditory functioning more comprehensively. Acoustic reflexes that elicited between 70 dB and 90 dB of the behavioural PT threshold were regarded as being within the normal range. Acoustic reflexes above 90 dB of the behavioural PT threshold were regarded as being elevated.

### 3.6.2.2 Distortion product otoacoustic emissions

Distortion product otoacoustic emissions (DPOAE) were measured using AuDX Bio-Logic OAE equipment. DPOAEs were measured using the Vanderbilt DPOAE diagnostic protocol in the frequency spectrum 634 Hz to 6347 Hz.

Details of the protocol were as follows:

- ❖ L1 = 65 dB SPL; L2 = 55 dB SPL
- ❖ F1/F2 ratio: 1.2
- ❖ Number of octaves: 4
- ❖ Number of sweeps per set: 25

To be regarded as a DPOAE, the following analyzing strategies were employed:

- ❖ The amplitude of the DPOAE was within the boundaries of the Vanderbilt 65/55 95<sup>th</sup> percentile reference set as illustrated in Figure 3.1.
- ❖ The noise floor (NF) level did not exceed 3dB SPL (Hall & Mueller, 1997).
- ❖ The difference between the DP emission and the NF level was equal to, or larger than 10 dB (that is DP-NF >10 dB).

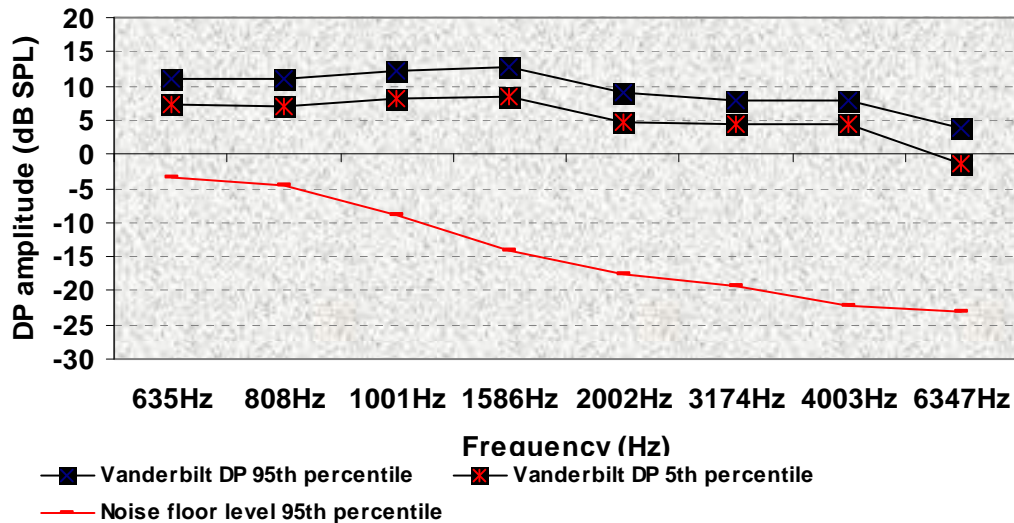


Figure 3.1: Vanderbilt 65/55 95<sup>th</sup> percentile normative values

In addition, the value of the DP/NF difference was categorized according to the criteria presented in Table 3.4.

**Table 3.4: Criteria for DP/NF difference**

DP-NF difference	Outcome
< 6dB	Absent DPOAE
6-9dB	Present DPOAE, but abnormal
>10dB	Present DPOAEs

Adapted from Hall & Mueller (1997)

### 3.6.2.3 Behavioural pure tone audiometry

Behavioural PT air conduction thresholds were obtained using a GSI 68 Diagnostic Audiometer. The acoustic stimuli were presented through TDH 39 supra-aural headphones. The behavioural PT thresholds were determined in the frequency range 0.5 kHz to 4 kHz.

### 3.6.2.4 Auditory brainstem response

The state of awareness for each subject was evaluated prior the ABR recordings and rated according to a rating scale (Appendix F).

The click-evoked and 0.5 kHz tone burst (TB) ABR thresholds were obtained using the VS ABR system as well as an ABR system with conventional technology, i.e. the Bio-Logic Navigator Pro system (BL).

Behavioural electrophysiological thresholds using the VS and the BL ABR systems were obtained from a group of five normal hearing young adults, aged between 20 and 28 years, prior to ABR testing in the research sample. These behavioural electrophysiological click-evoked and 0.5 kHz TB thresholds served as the reference values for the research sample. The method for selecting these subjects, the procedures and material implemented as well as the reference values for both ABR systems are summarized in Table 3. 5.



**Table 3.5: Summary of methodology followed to obtain reference values for the VS and BL ABR systems**

<b>Selection criteria</b>	<ul style="list-style-type: none"><li>❖ Normal middle ear functioning Subjects in the normative group were required to have normal middle ear functioning since any middle ear pathology could influence the accuracy of pure tone thresholds (Hall &amp; Mueller, 1997).</li><li>❖ Hearing sensitivity The normative group was required to present with normal hearing sensitivity (&lt;15dB HL) in the frequency spectrum 0.5 kHz-4 kHz. These frequencies were selected to provide corresponding points in comparing the data to the click-evoked as well as the 0.5 kHz tone burst ABR procedures</li><li>❖ Constraints in terms of time</li></ul>
<b>Selection procedures</b>	<ul style="list-style-type: none"><li>❖ A convenient sampling process was followed because the sample consisted of acquaintances of the researcher and the student body of the Department of Communication Pathology at the University of Pretoria (Maxwell &amp; Satake, 2006:96)</li><li>❖ Selection procedures included:<ul style="list-style-type: none"><li>- The availability and willingness to take part in the study was enquired</li><li>- If subject was willing to participate, the informed consent letter was given (Appendix G) and a suitable date and time was scheduled for the testing to be done</li><li>- At the day of testing otoscopy, tympanometry and behavioural pure tone audiometry was conducted. If subject presented with normal hearing sensitivity and normal tympanometric results, the researcher proceeded to the behavioural electrophysiological thresholds obtained with the VS and the BL ABR systems using click stimuli as well as 0.5 kHz tone burst stimuli.</li></ul></li></ul>
<b>Apparatus and protocols (Similar to the research sample)</b>	<ul style="list-style-type: none"><li>❖ Otoscopy: mini Heine 2000</li><li>❖ Tympanometry: GSI 33 middle ear analyzer</li><li>❖ Behavioural audiometry: GSI 38 Diagnostic</li><li>❖ VS and BL ABR systems: Similar to that of the research sample</li></ul>



	<ul style="list-style-type: none"><li>❖ Protocols: similar to the research sample</li></ul>
<b>Data collection procedures</b>	<ul style="list-style-type: none"><li>❖ Normative behavioural thresholds were obtained after behavioural pure tone audiometry was conducted; thus subjects remained in the soundproof booth. The researcher explained to each subject what was expected of him/her when introduced to the ABR systems. The researcher alternated between the ABR systems being employed first. After the ER-3A insert earphones of the ABR system employed firstly was inserted in the ear canals of the subject, click stimuli was presented monotonically at a supra-threshold intensity of 70dB nHL. Stimulation was then gradually descended in steps of 10dB until the subject indicated that the stimuli were no longer audible. At this stage the intensity was increased in steps of 5dB until the subject indicated that the stimuli were audible. This level was taken as the behavioural threshold. Click stimulation was followed by 0.5 kHz tone burst stimuli presentation bilaterally. After behavioural thresholds were obtained bilaterally for click and 0.5 kHz tone burst stimuli for the one system, the next system was employed following the same procedures.</li></ul>
<b>Data analysis procedures</b>	<ul style="list-style-type: none"><li>❖ The raw quantitative data was prepared and organized into a data set suitable for analysis (Neuman, 1997). The prepared data organized on Microsoft Excel XP worksheets were analyzed with statistical measures. The mean behavioural thresholds using the click and 0.5 kHz stimuli were obtained for both systems.</li></ul>
<b>Results (mean ABR reference values in dB nHL)</b>	<p><b><u>Click stimuli</u></b></p> <p><b>VS ABR system: Left ear = 3dB nHL; Right ear = 2 dB nHL</b></p> <p><b>BL ABR system: Left ear = 11 dB nHL; Right ear = 11 dB nHL</b></p> <p><b><u>0.5 kHz TB stimuli</u></b></p> <p><b>VS ABR system Left ear = 7 dB nHL; Right ear = 8 dB nHL</b></p> <p><b>BL ABR system Left ear = 5 dB nHL; Right ear = 5 dB nHL</b></p>

The VS ABR system consisted of the Integrity model V500 (version 4.50, R3 Research code) which was installed on a Dell laptop (Latitude, D 520; Windows XP operating system). The interface module (Integrity V500) has been designed for the acquisition and analysis of AER, including the click and the tone-evoked ABR. The communication between the data collecting module, the Vivolink (calibrated February 2008; serial number: VP 0187) happened wirelessly (via bluetooth) through the D-Link (model number DBT-122) which was inserted in the USB-port of the laptop. The new generation of pre-amplifiers, the Amplitrode (serial number ENG 9963) was connected to the Vivolink and consisted of an integrated pre-amplifier and electrode clip in a combined unit. This was affixed to Ambu Neuroline 720 disposable pre-jelled, foam-backed electrodes on the subject's forehead (Fz), and both mastoids. Insert earphones (ER-3A; Integrity insert earphones serial numbers: Right: 44747, Left: 44745) were connected to the Vivolink.

The BL ABR equipment consisted of a specialized hardware component (Navigator Pro Bio-Logic) that was connected to a laptop. The system was operated by a software package (BL Auditory Evoked Potentials version 2.3.0) specifically designed for the acquisition and analysis of auditory evoked responses (AER), including the click and tone-evoked ABR. Insert earphones (ER-3A; Bio Logic insert earphones serial numbers: Right: 35086, Left: 35095) were connected to the hardware component.

The acquisition parameters of the VS and BL ABR systems were identical, though technical differences regarding the filtering and the signal processing occurred. The specifications for the VS ABR system and the BL ABR system are presented in Table 3.6.

**Table 3.6: Acquisition parameters for the VS and BL ABR systems**

Specifications	VS ABR system	BL ABR system
<b>Amplification</b>	x100 000	x100 000
<b>Filters :</b> Settings	100-3000Hz	100-3000Hz
<b>Signal processing algorithm</b>	Kalman Weighted	Signal Averaging
<b>Number of sweeps</b>	2 runs of 2000 or 1 run of 4000 sweeps	2 runs of 2000 sweeps
<b>Analysis time:</b>		
Click stimuli	16ms	16ms
0.5 kHz tone burst stimuli	21.3ms	21.3ms
<b>Artifact rejection</b>	Not applicable	23.3uV

Stimuli parameters for the click-evoked and 0.5 kHz TB recorded stimuli were identical for both ABR systems. The specifications for the click and the 0.5 kHz TB stimulus are presented in Table 3.7.

### 3.7 Procedures

The audiological test battery and the ABR procedures were conducted by the researcher whom has acquired a B.Communication Pathology degree with specialization in Speech Therapy and Audiology.

The data that was obtained through the audiometric test battery, i.e. the tympanograms, ipsilateral acoustic reflexes, DPOAEs as well as behavioural PT audiometry results, were collected prior to the data collection of the ABR measurements. As there was a 2 month time difference between the two data collection dates, tympanometry was conducted prior to ABR measurement of

each subject to ensure normal middle ear functioning and to exclude subjects with any middle ear condition that could possibly influence the ABR results.

**Table 3.7: Stimuli parameters for VS and BL ABR systems**

Click-evoked ABR		0.5 kHz TB ABR	
Parameter	Settings	Parameter	Settings
Synchronism	Internal	Synchronism	Internal
Stimulus	Click	Stimulus	Tone burst
Stimulus rate	37.7/s	Stimulus rate	37.7/s
Ear tested	Left or Right	Frequency	0.5kHz
Polarity	Rarefaction	Duration	2ms (2-0-2 cycles)
Intensity scale	dB HL	Envelope (ramping)	Blackman
Intensity	Starting at 70dB nHL	Ear tested	Left or Right
		Polarity	Alternating
		Intensity scale Intensity	dB HL
		Intensity	Starting at 70dB nHL

### 3.7.1 Data collection procedures: immittance, distortion product

#### otoacoustic emissions and behavioural pure tone audiometry

Immittance, DPOAE measurements and behavioural PT audiometry were conducted in a double walled soundproof booth at the Speech Therapy department of the Pretoria School for Children with Cerebral Palsy.

#### 3.7.1.1 Immittance

After careful probe fitting in the subject's ear canal, tympanometry was first conducted with immediately following ipsilateral acoustic reflexes.

#### 3.7.1.2 Distortion product otoacoustic emissions

DPOAE measurements were conducted after immittance measurements. After the probe was fitted in the subject's ear, he/she was encouraged to remain as quiet as possible.



### **3.7.1.3 Behavioural pure tone audiometry**

PT stimuli were presented monotonically, commencing at 40 dB HL if the subject's hearing status was unknown. In some cases the previous records of PT audiometry results were available to the researcher, in which cases PT audiometry commenced 20 dB above the determined PT thresholds. Behavioural PT thresholds were determined descending intensity steps of 10dB and ascending steps of 5 dB and defined by a 50% response rate at a specific intensity level.

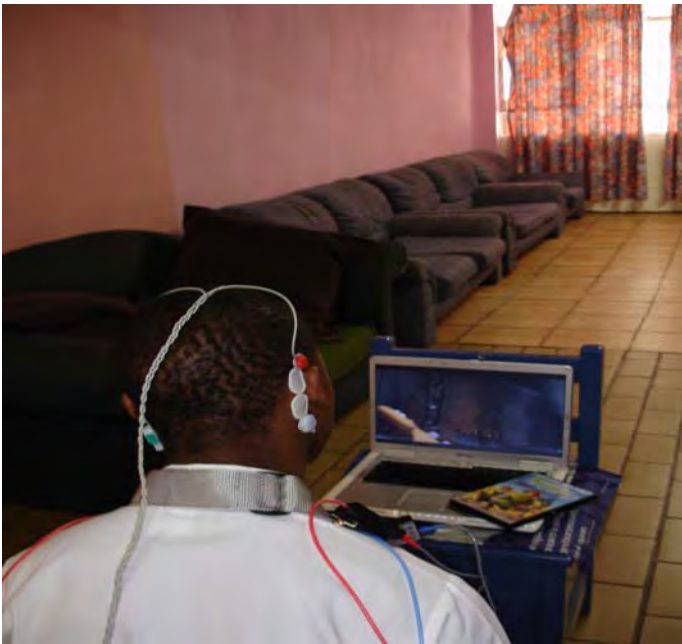
### **3.7.2 Data collection procedures: auditory brainstem response**

ABR measurements were conducted in a quiet room at the Pretoria School for children with cerebral palsy. Prior to each subject's assessment, the noise level was measured and monitored with a sound level meter (Extech instruments 407730, serial number 9590505). The ABR recording was also preceded by tympanometry in order to ensure that no middle ear pathology developed since auditory functioning was assessed 2 months earlier.

Simultaneous click-evoked recordings using the VS and BL ABR systems were conducted followed by simultaneous 0.5 kHz TB recordings with both systems. The recordings of the different ABR systems were conducted simultaneously in order to evaluate both systems as objectively as possible. As discussed in the research design section, this unique setup was imperative in order to ensure and maintain an equivalent test condition in terms of EEG, myogenic activity and environmental noises for both systems. This set-up is illustrated in Photos 3.2 to 3.4. Furthermore, the researcher alternated the VS and BL ABR systems between the left and right ears of the subjects to eliminate the order effect.



**Figure 3.2: Position of the ABR systems (VS ABR system to the left, BL ABR system to the right)**



**Figure 3.3 Position of the ABR electrodes as seen from behind (Inverting electrode of the BL ABR system on the right ear of the subject; ground and the Invert electrodes of the VS ABR system on the right and left ear of the subject respectively)**



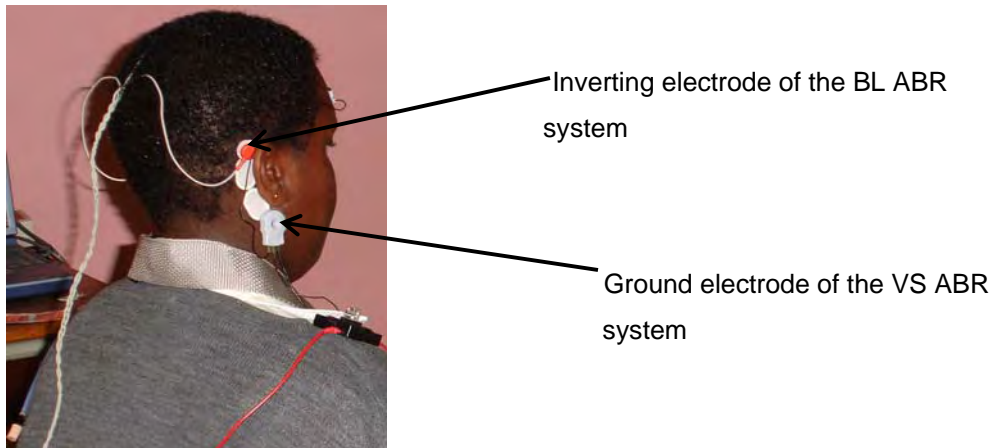
**Figure 3.4 Position of the ABR electrodes as seen from the front (Fz electrode of the VS ABR system beneath the Fz electrode of the BL ABR system; Vivolink attached to subject via cord)**

The acquisition parameters of both ABR systems were presented in Table 3.6. Although the VS and BL ABR systems utilized different technology for the amplification and filtering processes, similar settings were employed. The VS system utilized Kalman filtering (averaging) and 2000 to 4000 sweeps were averaged before the researcher manually stopped the averaging process. The BL system employed signal averaging and 2000 were averaged and automatically stopped. Artifact rejection was included in the signal averaging process of the BL system and not in the VS system because the effect of the Kalman filtering was investigated.

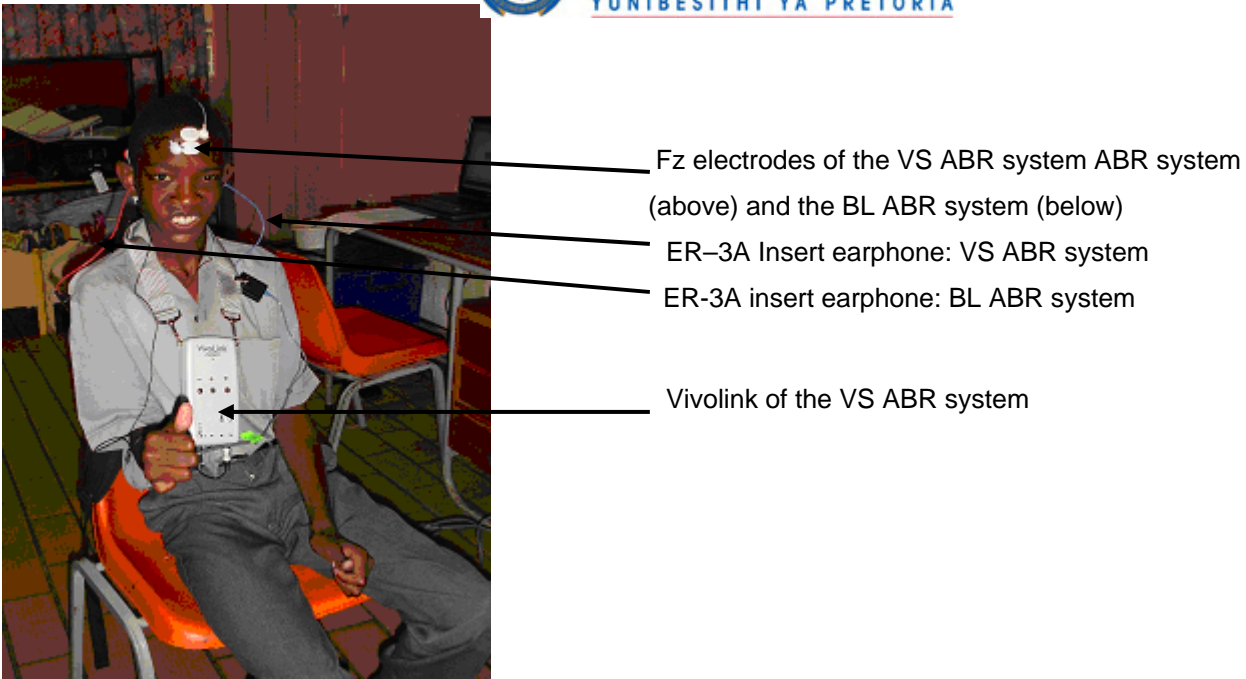
Prior the ABR recording the subject was asked to sit in a comfortable position on a chair or to remain in the wheelchair. An age-appropriate DVD was provided to the subjects during the ABR recording which the subject was encouraged to watch. The screen of the laptop from which the DVD was played was on a

comfortable height for each subject. During the ABR recording, the DVD was muted.

Prior the ABR recording, each subject's skin was prepared using alcohol prep swipes. Following the preparation of the skin, electrode discs were fixed to the forehead Fz (non-inverting), mastoid ipsilateral (inverting) and mastoid contra-lateral (ground) for each ABR system separately. The mastoid ipsilateral and mastoid contra-lateral data collection procedures were switched between reference and ground depending on the test side since it was a single channel recording. This setup is illustrated in Figure 3.5 and Figure 3.6 respectively. The impedance values were kept below 5 k $\Omega$ , with less than 3 k $\Omega$  difference between the electrodes. ER 3A -insert earphones of the VS and the BL ABR system were then placed in the subject's left and right ear canals.



**Figure 3.5: Position of the inverting and ground electrodes of the VS and BL ABR systems as seen from the side**



**Figure 3.6: Position of the Fz electrodes, as well as the ER- 3A insert earphones each ABR system**

ABR recording commenced as soon as the ER 3A-insert earphones of both systems were inserted in the left and right ear canals respectively. The click stimulus was first employed with both ABR systems. The 0.5 kHz TB stimulus was presented directly after a click-evoked threshold was determined by a specific ABR system. Stimulation (click and 0.5 kHz tone burst stimuli) was presented bilaterally at an above threshold intensity of 70 dB nHL. In cases where the behavioural PT indicated a moderate or severe hearing loss, stimulation was presented at an above threshold level of 80 dB nHL or 90 dB nHL. In order to establish ABR thresholds, the researcher descended in intensity steps of 10 dB and ascended in steps of 5 dB. However, in cases where there was a time constraint or the subject presented with consistent muscular activity, the researcher descended in intensity steps of 10 dB only to obtain the ABR threshold. The specific descending method of 10 dB and on occasion the ascending method of 5 dB was kept consistent between the click and 0.5 kHz TB recordings of each subject.

### **3.7.3 Procedures for analysis of auditory brainstem response**

Repeatability of at least two ABR waveforms had to be recorded in succession with the same measurement conditions, i.e. no change in stimuli, intensity, rate or polarity in one ear to be regarded as an ABR response (Hall, 2007). The presence of wave V of the ABR waveform was also confirmed by replication of the waveform. Wave V had to be observed in the same latency region in at least two separately averaged waveforms (Hall, 2007). The ABR threshold was taken at the last intensity level at which the ABR response was successfully repeated and the wave V was still identifiable. Furthermore, the recordings were analyzed offline by two clinical audiologists who are experienced in ABR recordings. This objective analysis was an attempt to ensure a minimum of problems in interpreting the responses.

### **3.7.4 Procedures for analysis of the recording time of the auditory brainstem response recordings**

The recording time of both systems was determined offline. In order to determine the recording time of the VS system the total amount of sweeps per recording (click-evoked or 0.5 kHz tone burst recording) up to one intensity lower than where the threshold were calculated and then divided by the rate of the stimuli (37.7s). The recording time of the BL system was calculated in a similar way, although the total artifact rejections per recording were also considered when calculating the total number of sweeps.

### **3.8. Data processing**

The raw data were organized on Microsoft XP Worksheets and were analyzed with statistical measures including descriptive and inferential statistics by the Department Statistics at the University of Pretoria. Whilst descriptive statistics includes the sorting, ordering and summarizing of data by means of graphs and tables, inferential statistics evaluates, contemplates and draws conclusions about the population from which the sample was drawn (Leedy & Ormrod, 2005; Neuman, 1997).

### **3.9 Data analysis**

In order to evaluate the clinical value of the Vivosonic Integrity ABR system in the auditory functioning of children with CP, each subject's individual performance was described for each procedure. The results obtained during acoustic reflex and DPOAE measurements assisted the researcher in describing the auditory status of the subject more comprehensively. The collective results for all the subjects were taken into account in analyzing and processing the behavioural PT, click-evoked and 0.5 kHz TB thresholds (both ABR systems).

The focus of this study was to compare the VS ABR system to the BL ABR system in terms of feasibility, threshold correspondence and recording time using click and 0.5 kHz TB stimuli. In terms of the threshold correspondence, the difference between the thresholds of the ABR systems and behavioural PT thresholds provided an indication of how close to each other the PT threshold the ABR thresholds were. All subject data were collectively analyzed using descriptive statistics. The analysis of the data was done at the Department of Statistics at the University of Pretoria. The data analysis included the following:

#### **3.9.1 Describing the feasibility and characteristics of an audiometric test battery**

- ❖ Determining the number of subjects in which ipsilateral acoustic reflexes, DPOAE measurements and behavioural PT audiometry were feasible.
- ❖ Determining the amount of present, elevated and absent ipsilateral reflexes per ear and per frequency for subjects with spastic CP, athetoid CP and microcephaly.
- ❖ Determining the amount of present, abnormally reduced and absent DPOAE by calculating the difference between the amplitude of the DPOAE and the noise floor level.
- ❖ Calculating the distribution of thresholds (mean, standard deviation and range) for 30 ears (n=15) per stimulus frequency as recorded by behavioural PT audiometry.

### **3.9.2 Comparing the VS ABR system with a conventional ABR system**

The VS ABR system was compared to the BL ABR system in terms of feasibility, electrophysiological thresholds, correspondence to behavioural PT thresholds and recording time when using click and 0.5 kHz TB stimuli. The data analysis for these comparisons is discussed under separate headings:

#### **3.9.2.1 Feasibility of the VS and BL ABR systems using click and 0.5 kHz tone burst (TB) stimuli**

- ❖ Comparing the successful VS ABR recordings using click and 0.5 kHz TB stimuli with the successful BL ABR recording using corresponding stimuli by using the Fisher exact p one-tailed test (Steyn, Smit, Du Toit & Strasheim, 1998).

#### **3.9.2.2 Electrophysiological thresholds of the VS and the BL ABR systems using click and 0.5 kHz TB stimuli**

- ❖ Comparing the electrophysiological thresholds obtained with the VS ABR system to the click-evoked and 0.5 kHz TB thresholds obtained BL ABR system in terms of the mean and range.

#### **3.9.2.3 Threshold correspondence of the VS and BL ABR systems to behavioural PT thresholds**

The organization of the threshold correspondence data for statistical analysis is presented in Figure 3.7.

- ❖ Determining the difference between the click-evoked threshold of the VS and BL ABR systems and behavioural thresholds for the corresponding ear at 2 kHz, 4 kHz and the average of 2 kHz and 4 kHz, for each subject for whom PT thresholds were obtained.
- ❖ Determining the normal distribution (mean, standard deviation and range) of the differences for the VS and BL ABR systems at 2 kHz, 4 kHz and the average of 2 kHz and 4 kHz.



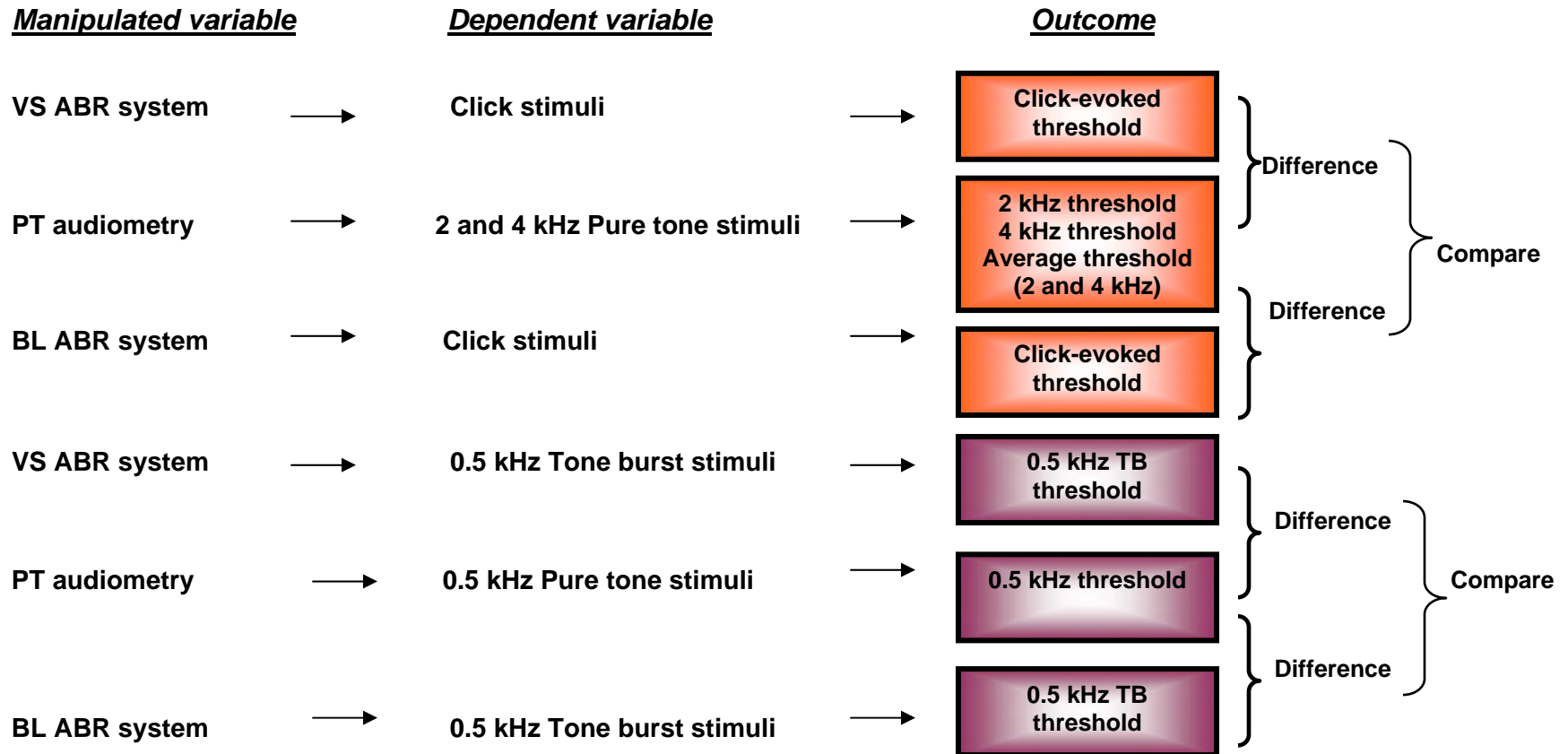


Figure 3.7: Organization of threshold difference data for statistical analysis

- ❖ Determine the difference between the 0.5 kHz TB threshold of the VS ABR and the behavioural PT threshold of the corresponding ear at 0.5 kHz, as well as the 0.5 kHz TB threshold of the BL system and the behavioural PT threshold of the corresponding ear at 0.5 kHz for each subject.
- ❖ Determining the normal distribution (mean, standard deviation and range) of the differences for the VS (15 ears) and BL ABR (15 ears) systems at 0.5 kHz.
- ❖ Establishing the statistical significance of the differences between the averages of the thresholds for 15 points (15 thresholds of the VS ABR system and 15 thresholds of the BL ABR system) per stimulus frequency by implementing inferential statistics. Two-sample comparisons were made between the differences obtained with the various measures as illustrated in Figure 3.2. The comparisons were done by using the Wilcoxon Signed Rank-Test (Mawell & Satake, 1997). This test was used because of the small sample size (Delpont, 1998). It is a powerful test in the sense that the determined p-value can indicate the magnitude and the direction (positive or negative) of the differences between the various data sets (Delpont, 1998; Johnstone & Pennypacker, 1993).

#### **3.9.2.4 Recording time of the VS and BL ABR systems using click and 0.5 kHz TB stimuli**

- ❖ Determining the recording time per subject and per measurement (i.e. per ear) using click and 0.5 kHz TB stimuli.
- ❖ Determining the normal distribution (mean, standard deviation and range) for the recording time of the VS and BL systems using click stimuli.
- ❖ Determining the average, standard deviation and range of normal deviation for the recording time of the VS and BL systems using 0.5 kHz TB stimuli
- ❖ Calculating the difference between the average recording times of the VS and BL systems using click and 0.5 kHz TB stimuli.
- ❖ Establishing the statistical significance of the differences between the mean recording times per stimulus frequency through inferential statistics.

### 3.10 Reliability and validity

Scientific research endeavors to draw valid and reliable conclusions about underlying relations among variables based on the empirical test procedures (Maxwell & Satake, 2007:40). Reliability refers to the consistency of a measurement (Drummond, 2003). In this research various procedures (behavioural PT thresholds and ABR thresholds) were used to measure the same phenomenon. The procedures were conducted with the same subjects using the same protocol.

Validity refers to the extent to which the instrument measures what it is supposed to measure and includes internal and external validity. Whereas internal validity relates to the issue whether independent variables were responsible for variations in the dependent variable, external validity pertains to the extent to which results can be generalized to one or more populations (Maxwell & Satake, 1997:44).

In this study the independent variables – behavioural PT audiometry and ABR measurements with the VS and BL ABR systems – were kept consistent by using the similar protocol throughout the research. Furthermore, as described in the research design, controlled variables were applied to the experimental setting. These controlled variables were applied to ensure a stable context for clear visualization of effects on the independent variables. The factors controlled by the researcher were:

- ❖ *Disability*: Subjects diagnosed with CP were selected for this study
- ❖ *Age*: Subjects between the ages of 12 to 18 years were selected for this study
- ❖ *Middle ear functioning*: Subjects were required to have normal middle ear functioning as defined by a Type A tympanogram

External validity in this study would particularly entail the problem of interpretation. A potential threat to this research lies in the comparison between the VS and BL ABR systems in the research sample. In order for the comparison

to be valid, both systems were subjected to similar test conditions. Therefore, different ears were used while the ABR recordings were conducted simultaneously in each subject.

Additionally, the threat to interpretation was reduced by introducing additional researchers to analyze ABR results objectively. Both of the additional researchers were well acquainted with electrophysiological auditory procedures, including the ABR.

### **3.11 Conclusion**

This chapter described the research process that was followed to determine the clinical value of the VS ABR system when assessing children with CP. Each procedure in the audiometric test battery was explained. It was also explained that data obtained from the auditory test battery procedures was exploited for descriptive purposes. Additionally, the protocols and procedures of ABR click-evoked and 0.5 kHz TB recordings utilizing different ABR systems were described. The importance of simultaneous ABR recordings of the different ABR systems was emphasized.

### **3.12 Summary**

The main aim and sub aims of the study were set out in this chapter, followed by a summary of the organization of the research process. The methodological framework for obtaining electrophysiological behavioural thresholds from a normative sample was described and was concluded by the inclusion of the normative values (click and 0.5 kHz TB stimuli) for the VS and the BL ABR systems. The methodological framework for the research sample was described, commencing with a discussion of the research design and ethical considerations. The criteria and procedures for selecting the subjects were discussed and a description of each subject was presented in table format. The apparatus, material and protocols that were implemented were described. Subsequently,

the procedures for analyzing and processing the data were discussed. The chapter concluded with a review of reliability and validity in relation to this study.

## Chapter 4

# RESULTS

*The aim of this chapter is to present the results of the empirical research.*

### 4.1 Introduction

To determine the clinical value of the Vivosonic Integrity (VS) auditory brainstem response (ABR) system when assessing auditory functioning in children with cerebral palsy (CP) different sets of data collection and analysis procedures were required. This chapter provides the results of the empirical research according to the sub-aims as discussed in Chapter 3.

### 4.2 Sub-aim 1 results: Characteristics and feasibility of an audiometric test battery in children with cerebral palsy

The first sub-aim focused on the applicability of the auditory test battery in a small sample of children with CP. The test battery in this study consisted of immittance and distortion product otoacoustic emissions (DPOAE), and behavioural pure tone (PT) audiometry. In the subsequent text, the results of each auditory procedure are provided according to its feasibility and characteristics in this sample. Table 4.1 provides a summary of the feasibility of each auditory procedure in the sample of 15 subjects.

Within Table 4.1 results obtained from each procedure have been categorized according to “reliable results obtained”; “unreliable results obtained” and “no results obtained”. For tympanometry measurements the term “reliable results” suggested that a tympanogram with clear indication of the middle ear pressure, compliance and middle ear volume was obtainable from the subject. For acoustic reflexes the term “reliable results” implied that acoustic reflexes were elicited at each test frequency, regardless of the intensity at which the reflex was elicited. In cases where acoustic reflexes could not be elicited due

to excessive muscle movements or due to a profound hearing loss, results were noted as “no results obtained”. For DPOAE measurements “reliable results” suggested that emissions could have been elicited and that emissions were present with normal or abnormal amplitudes. In cases where emissions could not have been elicited due to excessive muscular movements or due to a profound hearing loss results were noted as “no results obtained”. For behavioural PT audiometry “reliable results obtained” suggested that subjects responded consistently to pure tone stimuli. In cases where subjects responded inconsistently to PT stimuli, results were noted as unreliable.

The feasibility of the click-evoked and 0.5 kHz tone burst (TB) ABR recordings by means of the VS ABR and the Bio Logic Navigator Pro (BL) ABR systems is also included in this table. Reliable results obtained with the click-evoked and 0.5 kHz TB ABR procedures indicate that the ABR wave V was with repetition obtainable at the lowest intensity level that was regarded as the threshold in nHL. In cases where the ABR wave V was absent or where muscle activity was excessive, results were noted as “no results obtained”.

#### **4.2.1 Immittance measurements**

Immittance measurements in this study consisted of tympanometry and ipsilateral acoustic reflexes. As demonstrated in Table 4.1, tympanometry was conducted and measurable in 15/15 of the subjects. All the subjects (100%) presented with normal middle ear functioning as defined by a type A tympanogram.

Tympanometry was followed by ipsilateral acoustic reflex measurements. Although it was conducted in 15 subjects, Subject 15 was not testable due to persistent involuntary movements which caused continuous high levels of internal noise. Acoustic reflex measurements were therefore obtained in 14/15 subjects.



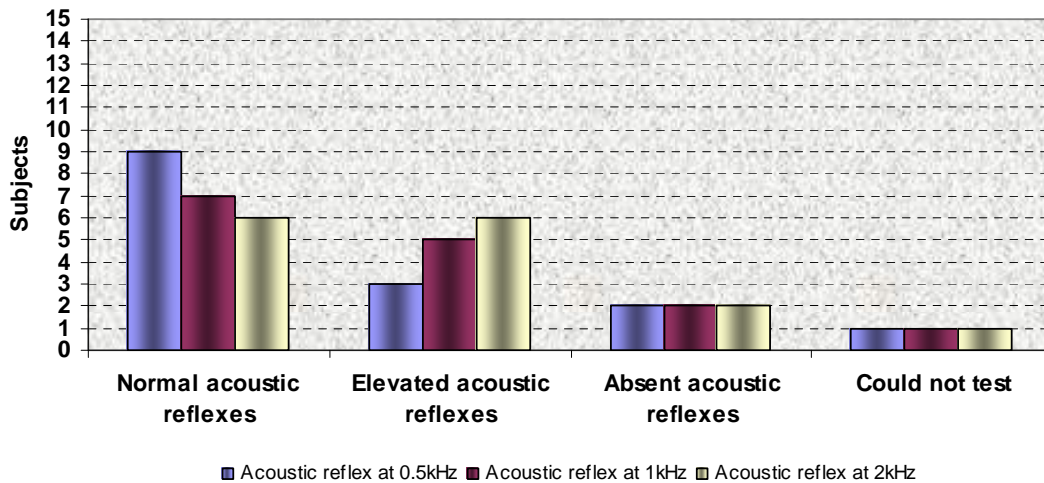
**Table 4.1: A summary of the feasibility of the various auditory procedures employed in the current study**

Subject	Type of CP	Auditory procedures							
		Tympanometry	Acoustic reflexes	DPOAE	Behavioural PT audiometry	Click-evoked ABR BL ABR VS ABR	0.5kHz TB ABR BL ABR VS ABR		
1	Spastic	Y	Y	Y	Y	Y	Y	Y	Y
2	Spastic	Y	Y	Y	Y	Y	Y	Y	Y
3	Microcephaly	Y	Y	Y	Y	Y	Y	0	Y
4	Spastic	Y	Y	Y	Y	Y	Y	Y	Y
5	Athetosis	Y	Y	Y	Y	Y	Y	Y	Y
6	Spastic	Y	Y	Y	X	Y	Y	Y	Y
7	Spastic	Y	Y	Y	X	Y	Y	Y	Y
8	Athetosis	Y	Y	Y	X	Y	Y	Y	Y
9	Spastic	Y	Y	Y	X	Y	Y	Y	Y
10	Spastic	Y	Y	Y	Y	Y	Y	Y	Y
11	Spastic	Y	Y	Y	Y	Y	Y	Y	Y
12	Spastic	Y	Y	Y	X	0	Y	0	Y
13	Spastic	Y	Y	Y	X	0	Y	0	Y
14	Athetosis	Y	Y	Y	X	0	0	0	0
15	Athetosis	Y	0	0	X	0	0	0	0

Key: Y = Reliable results obtained (= X = unreliable/inconsistent results; 0 = no results obtained)

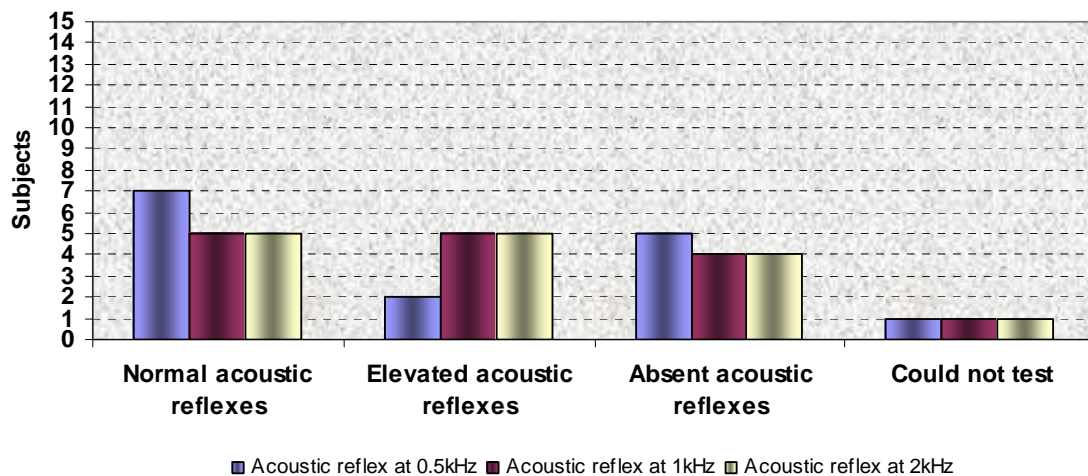


Frequency and ear specific acoustic reflex data were categorized in terms of normal, elevated and absent reflexes as discussed in Chapter 3. As this procedure was unsuccessful in Subject 15, another category, 'Could not test', was created. Right and left ear data are presented according to these categories in Figures 4.1 and 4.2 respectively.



**Figure 4.1: Distribution of right ipsilateral acoustic reflexes**

As shown in Figures 4.1 and 4.2 the majority of subjects (9/15 and 7/15) presented with normal acoustic reflexes at 0.5 kHz bilaterally.



**Figure 4.2: Distribution of left ipsilateral acoustic reflexes**

Five subject (n=15) presented with elevated acoustic reflexes at 1 kHz in the left and the right ears whilst 6/15 and 5/15 subjects presented with elevated acoustic reflexes at 2 kHz. Two subjects presented with absent acoustic reflexes at 0.5 kHz, 1 kHz and 2 kHz in the right ear (Subject 5 and Subject 14). In the left ear, four subjects (Subjects 5, 6, 12 and 14) presented with absent acoustic reflexes at 1 kHz and 2 kHz, whilst the acoustic reflexes at 0.5 kHz were absent in five subjects (Subjects 3, 5, 6, 12 and 14).

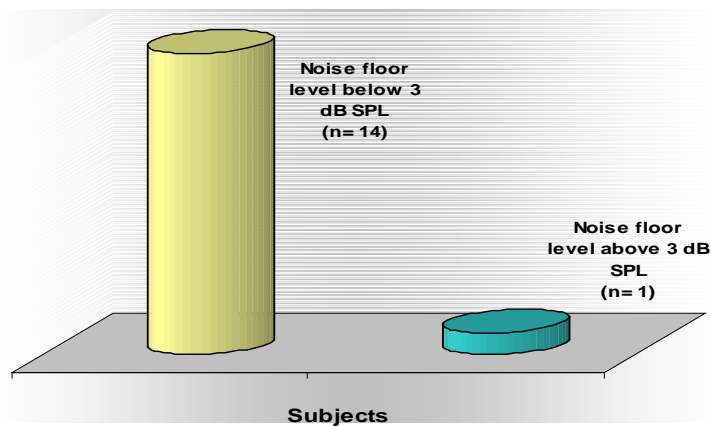
Subject 5 and Subject 14 were the only ones whom presented with absent acoustic reflexes bilaterally. Both these subjects were diagnosed with the athetoid type of CP. Table 4.2 presents a summary of the acoustic reflexes obtained in the different CP sub-groups of the research sample.

**Table 4.2: Summary of ipsilateral acoustic reflexes obtained in different CP sub-groups of the research sample**

<b>Spastic CP (n=10; 20 ears)</b>		
	<b>Left ear (30 acoustic reflexes)</b>	<b>Right ear (30 acoustic reflexes)</b>
Normal	15/30	19/30
Elevated	9/30	11/30
Absent	6/30	-
Could not test	-	-
<b>Athetosis CP (n=4; 8 ears)</b>		
	<b>Left ear (12 acoustic reflexes)</b>	<b>Right ear (12 acoustic reflexes)</b>
Normal	2/12	3/12
Elevated	1/12	-
Absent	6/12	6/12
Could not test	3/12	3/12
<b>Microcephaly (n=1; 2 ears)</b>		
	<b>Left ear (3 acoustic reflexes)</b>	<b>Right ear (3 acoustic reflexes)</b>
Normal	-	-
Elevated	2/3	3/3
Absent	1/3	-
Could not test	-	-

#### 4.2.2 Distortion product otoacoustic emissions

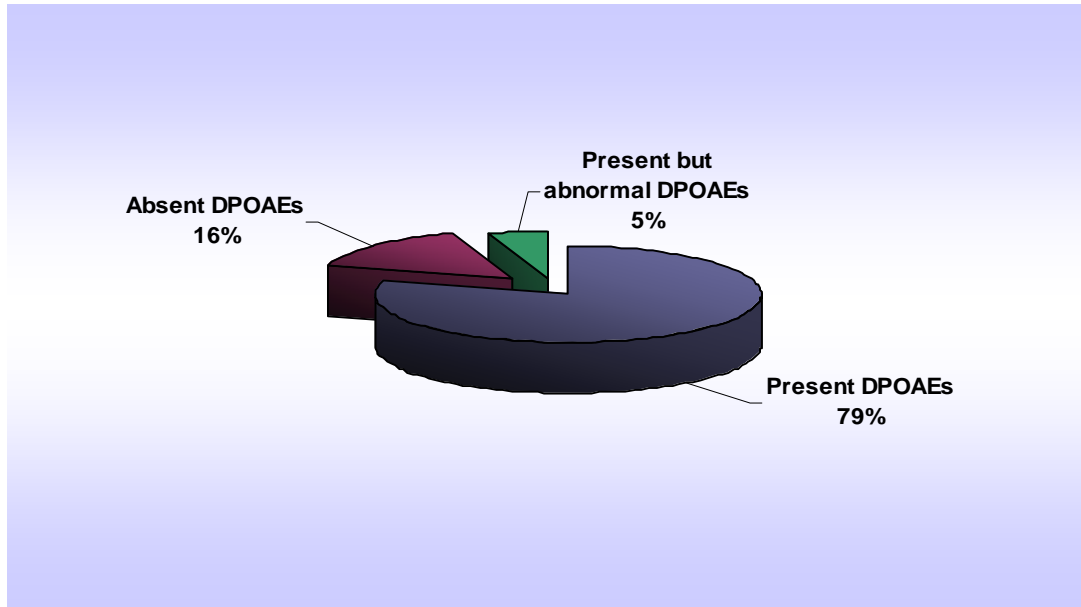
DPOAE measurements were conducted after the acoustic reflex procedure. Although DPOAE were administered in all the subjects ( $n=15$ ), results were only obtained in 14/15 subjects as shown in Table 4.1. Figure 4.3 illustrates that, whilst acceptable noise floor levels (i.e. below 3 dB SPL) were attained during the DPOAE measurements in the majority of the research sample ( $n=14$ ), the noise floor levels exceeded 3 dB SPL in one subject (Subject 15). Subject 15 presented with consistent involuntary movements of especially the neck and jaw.



**Figure 4.3: Noise floor levels attained during DPOAE measurements ( $n=15$ )**

A total of 224 DPOAE frequencies were measured for 28 ears ( $n=14$ ). Figure 4.4 provides an illustration of measured DPOAEs that were present, abnormally reduced and absent.

As shown in Figure 4.4, 35 of 224 emissions (16%) were absent. There was a greater preponderance of absent emissions in the 2002 Hz to 6346 Hz frequency region (46%) followed by 31% and 23% in the low (635 Hz to 808 Hz) and mid frequencies (1001 Hz to 1586 Hz) respectively. Two subjects (Subject 5 and Subject 14) presented with absent emissions across the frequency spectrum. Both of these subjects presented with the athetoid type of CP as shown in Table 4.1.

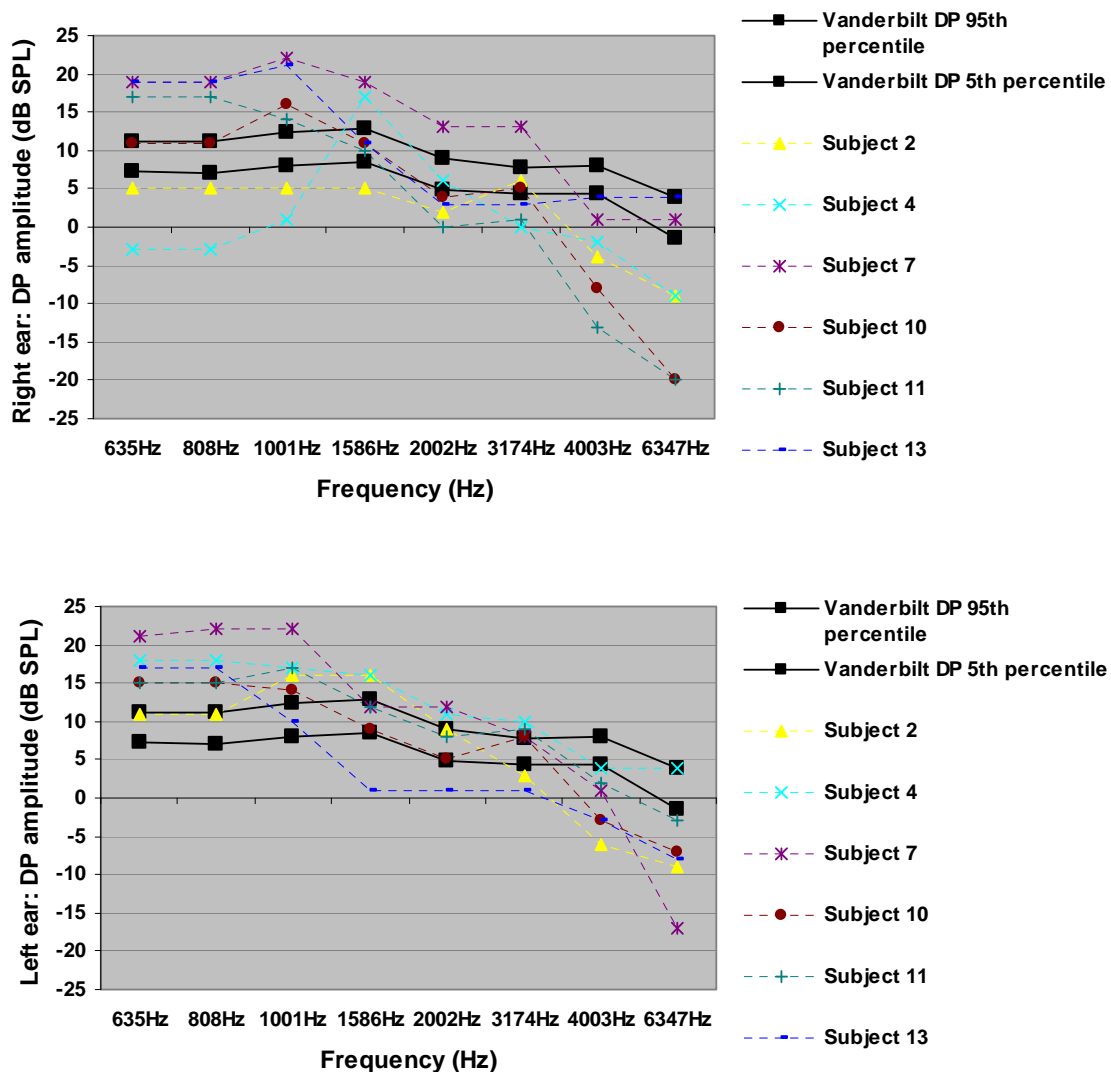


**Figure 4.4: Distribution of DPOAE in the current research as specified by Distortion product (DP) – Noise Floor (NF) criteria (DP-NF < 6dB = absent DPOAE; DP-NF = 6-9dB = present, but abnormally reduced DPOAE; DP-NF > 10dB = present DPOAE)**

Only a small portion (11 out of 224 or 5%) of the emissions was present, though abnormally reduced. The majority of the reduced emissions (45%) were noted in the high frequencies (2002 Hz to 6346 Hz) followed by 36% and 18% in the low (635 Hz to 808 Hz) and mid (1001 Hz to 1586 Hz) frequencies respectively. The majority of the DPOAEs (79%) occurred within the normal amplitude range as specified by the Vanderbilt criteria. There was, however, a percentage of emissions with amplitudes (11% in the left ear and 8% in the right ear) that exceeded the Vanderbilt 95<sup>th</sup> percentile values at certain frequencies. This occurred in six subjects as illustrated in Figure 4.5.

Interestingly, elevated DPOAEs were only obtained from subjects diagnosed with spastic CP. Elevated DPOAE amplitudes were obtained from 6/10 of spastic CP subjects. As depicted in Figure 4.5, the amplitude of the emissions was especially elevated between 635 Hz and 1586 Hz bilaterally for Subject 7, Subject 11 and Subject 13. The amplitude of the emissions was elevated in

either the left or the right ear at similar frequencies for Subject 2, Subject 4 and Subject 10.



**Figure 4.5: DPOAEs with elevated amplitudes in at least one ear of a subject**

To investigate the extent of the increased DPOAE amplitudes obtained in these subjects, the difference between the amplitudes of the DPOAE and the 95<sup>th</sup> percentile of the Vanderbilt criteria was calculated for each test frequency and is displayed in Table 4.3 and Table 4.4. As shown in Table 4.3 and Table 4.4 the amplitude differences were larger for the low and mid frequencies (635 Hz to 1586 Hz) for these subjects than the differences for the higher frequencies (2002 Hz to 6347 Hz).



**Table 4.3: The difference between the DPOAE amplitude (dB SPL) of the left ear and the 95th percentile of the Vanderbilt criteria at various test frequencies of subjects in whom elevated emissions were obtained**

Frequency	95 <sup>th</sup> Percentile	Subject 2		Subject 4		Subject 7		Subject 10		Subject 11	
		DP Amplitude	Difference	DP Amplitude	Difference	DP Amplitude	Difference	DP Amplitude	Difference	DP Amplitude	Difference
635Hz	11.16	11	-0.16	<b>18</b>	<b>6.84</b>	<b>21</b>	<b>9.84</b>	<b>15</b>	<b>3.84</b>	<b>15</b>	<b>3.84</b>
808Hz	11.05	11	-0.05	<b>18</b>	<b>6.95</b>	<b>22</b>	<b>10.95</b>	<b>15</b>	<b>3.95</b>	<b>15</b>	<b>3.95</b>
1001Hz	12.28	<b>16</b>	<b>3.72</b>	<b>17</b>	<b>4.72</b>	<b>22</b>	<b>9.72</b>	<b>14</b>	<b>1.72</b>	<b>17</b>	<b>4.72</b>
1586Hz	12.76	<b>16</b>	<b>3.24</b>	<b>16</b>	<b>3.24</b>	12	-0.76	9	-3.76	12	-0.76
2002Hz	8.9	9	0.1	<b>11</b>	<b>2.1</b>	<b>12</b>	<b>3.1</b>	5	-3.9	8	-0.9
3174Hz	7.75	3	-4.75	<b>10</b>	<b>2.25</b>	8	0.25	8	0.25	9	1.25
4003Hz	7.91	-6	-13.91	4	-3.91	1	-6.91	-3	-10.91	2	-5.91
6347Hz	3.95	-9	-12.95	4	0.05	-17	-20.95	-7	-10.95	-3	-6.95

**Key:**  Indicates DP amplitudes (in dB SPL) that exceeded the 95<sup>th</sup> percentile of the Vanderbilt criteria and the extent of the difference



**Table 4.4: The difference between the DPOAE amplitudes (dB SPL) of the right ear and the 95th percentile of the Vanderbilt criteria at various test frequencies of subjects in whom elevated emissions were obtained**

Frequency	95 <sup>th</sup> Percentile	Subject 2		Subject 4		Subject 7		Subject 10		Subject 11	
		DP Amplitude	Difference	DP Amplitude	Difference	DP Amplitude	Difference	DP Amplitude	Difference	DP Amplitude	Difference
635Hz	11.16	5	-6.16	-3	6.84	<b>19</b>	<b>7.85</b>	<b>11</b>	<b>0.16</b>	<b>17</b>	<b>5.84</b>
808Hz	11.05	5	-6.05	-3	6.95	<b>19</b>	<b>7.95</b>	<b>11</b>	<b>0.5</b>	<b>17</b>	<b>5.95</b>
1001Hz	12.28	5	-7.28	1	4.72	<b>22</b>	<b>9.72</b>	<b>16</b>	<b>3.72</b>	<b>14</b>	<b>1.72</b>
1586Hz	12.76	5	-7.76	<b>17</b>	<b>4.24</b>	<b>19</b>	<b>6.24</b>	11	-1.76	10	-12.76
2002Hz	8.9	2	-6.9	6	-2.9	<b>13</b>	<b>4.1</b>	4	-4.9	0	-8.9
3174Hz	7.75	6	-1.75	0	-7.75	<b>13</b>	<b>4.25</b>	5	-2.25	1	-6.75
4003Hz	7.91	-4	-11.91	-2	-9.91	1	-6.91	-8	-15.91	-13	-20.91
6347Hz	3.95	-9	-12.95	-9	-12.95	1	-2.95	-20	-23.95	-20	-23.95

**Key:**  Indicates DP amplitudes (in dB SPL) that exceeded the 95<sup>th</sup> percentile of the Vanderbilt criteria and the extent of the difference

### 4.2.3 Behavioural pure tone audiometry

Behavioural pure tone (PT) audiometry was conducted between 0.5 kHz to 4 kHz. Table 4.5 provides behavioural PT thresholds (left and right ears) for each subject (n=15 subjects, 30 ears).

**Table 4.5: Behavioural PT thresholds (in dB HL) for each subject (n=15)**

Subject	Left ear PT threshold (dB HL)				Right ear PT threshold (dB HL)			
	0.5 kHz	1 kHz	2 kHz	4 kHz	0.5 kHz	1 kHz	2 kHz	4 kHz
<b><u>Spastic CP</u></b>								
1	5	10	5	10	5	10	15	20
2	5	0	5	5	5	5	5	10
4	0	0	0	0	0	0	0	0
6	5	0	10	15	10	5	10	0
7	10	15	5	5	10	10	15	15
9	0	10	10	5	0	0	5	5
10	0	5	5	10	0	10	0	5
11	0	0	10	10	5	5	0	5
12	10	15	15	5	5	5	20	5
13	0	10	5	5	5	0	0	0
<b><u>Athetotic CP</u></b>								
5	25	40	60	65	25	40	60	65
8	5	0	10	5	5	5	5	10
14	0	5	5	0	10	10	5	5
15	55	55	55	55	40	40	65	70
<b><u>Microcephaly</u></b>								
3	10	0	5	10	10	5	10	10

The consistency of each subject's responses to the PT stimuli played an integral role in the study, especially in determining the correspondence of the electrophysiological thresholds of each ABR system to the PT stimuli. Accordingly, the subjects were categorized according to the consistency/reliability of their behavioural responses as shown in Table 4.6.

As depicted in Table 4.6 inconsistent behavioural responses were obtained from three subjects with athetosis with only Subject 5 responding reliably. Behavioural responses of the subjects with spastic CP were equally distributed between Group A (5 subjects) and B (5 subjects). The only subject with microcephaly, Subject 3, responded consistently to the PT stimuli.



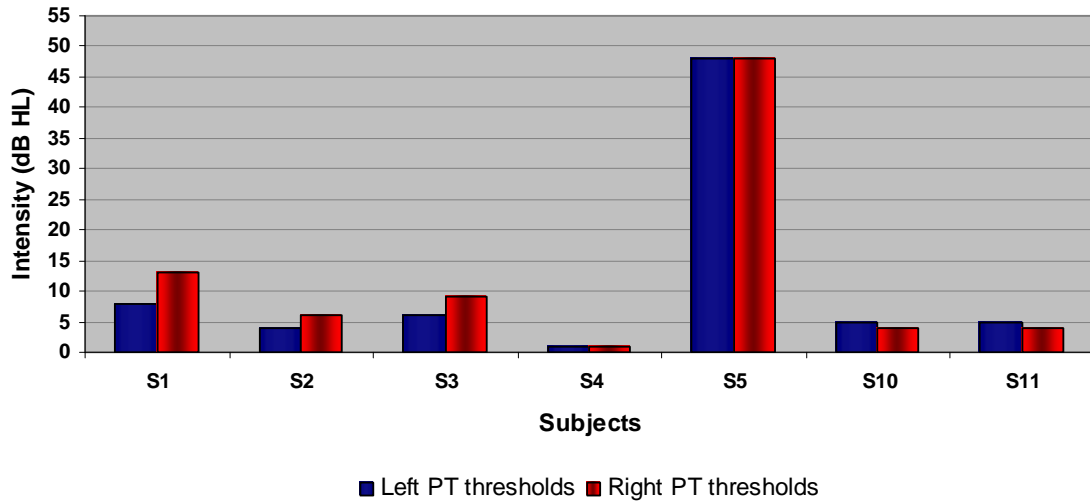
**Table 4.6: Consistency of behavioural PT responses (0.5 kHz to 4 kHz)  
(n=15 subjects)**

Subject	GROUP A (Subjects with consistent responses)	GROUP B (Subjects with inconsistent responses)
<b><u>Spastic CP</u></b>		
1	X	
2	X	
4	X	
6		X
7		X
9		X
10	X	
11	X	
12		X
13		X
<b><u>Athetotic CP</u></b>		
5	X	
8		X
14		X
15		X
<b><u>Microcephaly</u></b>		
3	X	

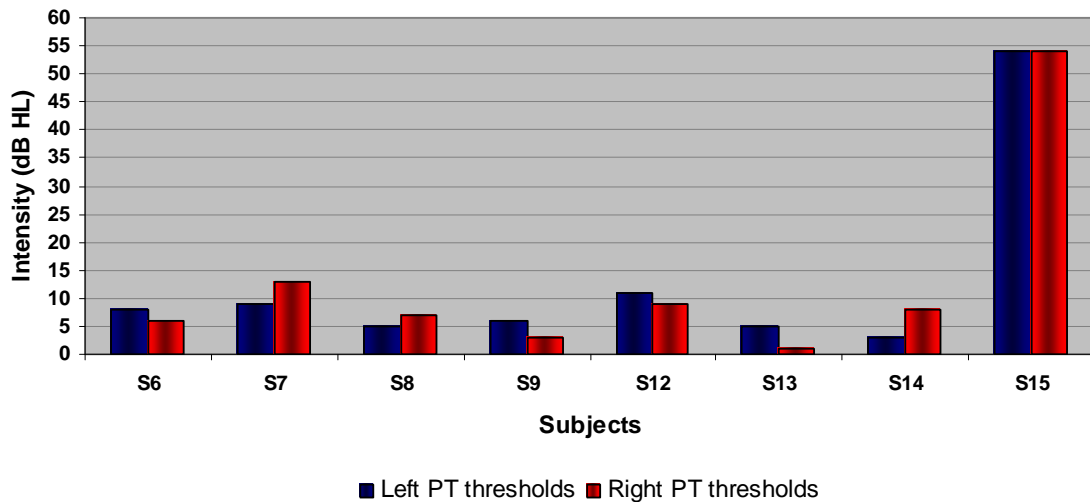
The mean behavioural PT thresholds of subjects in Group A are presented in Figure 4.6. Investigating the mean behavioural PT thresholds of subjects in Group A revealed that the inter-aural differences were slight and ranged between 0 dB and 3 dB. The majority of the behavioural thresholds obtained from subjects in Group A were equal to, or less than 10 dB HL with the exception of Subject 5. This subject presented with a moderate to severe high frequency hearing loss (25 dB HL to 65 dB HL) bilaterally. Subsequently, the SD of the mean PT thresholds across the frequency spectrum varied between 13 dB HL to 19 dB HL and 11 dB HL to 22 dB HL in both ears.

Although the subjects in Group B responded inconsistently to behavioural PT stimuli, thresholds (or rather minimal response levels) were still obtained and are reported below. The mean behavioural thresholds of subjects in Group B are presented in Figure 4.7. In this group, the inter-aural differences ranged between 0 dB and 5 dB. The majority of the thresholds were equal to, or less than 15 dB

HL, with the exception of Subject 15. This subject presented with a moderate to severe high frequency hearing loss (mean behavioural thresholds of 53 dB HL and 48 dB HL in the left and right ear respectively).



**Figure 4.6: Subjects in Group A: Mean behavioural PT thresholds for 0.5 kHz to 4 kHz**



**Figure 4.7: Subjects in Group B: Mean behavioural PT thresholds for 0.5 kHz to 4 kHz**

### **4.3 Sub-aim 2 results: Comparing the Vivosonic Integrity ABR system with a conventional ABR system**

The Vivosonic Integrity ABR system (VS) was compared to a conventional ABR system, in this instance the Bio Logic Navigator Pro system. The VS system was compared to the BL ABR system in terms of the feasibility, the threshold correspondence to behavioural PT thresholds as well as the recording time. The results of each of these comparisons are presented separately in the following section. Prior to the presentation of these results, information regarding the state of each subject's awareness, the sound level that was measured prior to each ABR recording and the inter-aural differences of the ABR components (that is the latency differences between the wave I, wave V and wave I-V for each ear i.e. for each ABR system) is presented in Table 4.7.

As shown in Table 4.7, all the subjects were awake during the ABR recordings. Whilst the majority of the subjects presented with sporadic muscular movements, Subject 12, Subject 13 and Subject 14 displayed constant muscular movements. The environmental noise was minimal (below 40 dB A) prior to each ABR recording as measured by the sound level meter. The sound level meter did not test below 40 dB A.

Because the VS and the BL ABR systems were compared to each other by comparing the left and right ears, it was important to determine inter-aural differences of the ABR wave I, wave V and the absolute latency (wave I-V) for each subject. From Table 4.7 it is apparent that the mean inter-aural differences for wave I, wave V and wave I-V were slightly larger when compared to the mean inter-aural differences obtained from normal hearing subjects with no CP (wave I =  $-0.02 \pm 0.08$ ; wave V =  $0.00 \pm 0.11$ ; wave I-V =  $0.00 \pm 0.11$ ) (Hall, 2007).

#### **4.3.1 Feasibility of the VS and BL ABR systems using click and 0.5 kHz TB stimuli**

As stated in Chapter 3, the VS and BL ABR systems were simultaneously conducted in all 15 subjects. The VS ABR system was implemented for 9/15 right and 6/15 left ears whereas 6/15 right ears and 9/15 left ears were tested with the BL system.

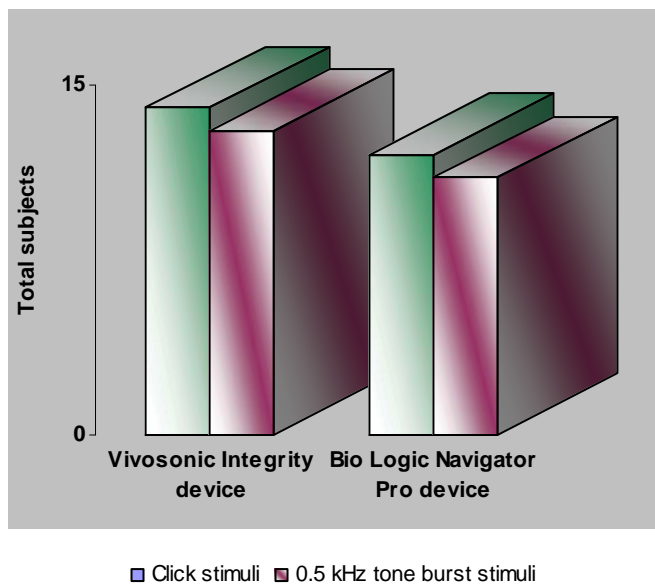
**Table 4.7: Information related to the state of awareness, sound level and inter-aural latency differences (n=15 subjects)**

Subject	State of awareness	Sound level (dB A)	Inter-aural difference (ms)		
			Wave I	Wave V	Wave I-V
1	Awake, sporadic movements	<40	0.1	1	1
2	Awake, sporadic movements	<40	0.1	0.1	0
3	Awake, sporadic movements	<40	0.6	0.1	0.5
4	Awake, sporadic movements	<40	**	0.2	**
5	Awake, sporadic movements	<40	0.2	0.3	0.1
6	Awake, sporadic movements	<40	0	0	0.1
7	Awake, sporadic movements	<40	0.1	0.2	0.4
8	Awake, sporadic movements	<40	0	0	0
9	Awake, sporadic movements	<40	0.1	0.1	0.1
10	Awake, sporadic movements	<40	0.1	0.1	0.1
11	Awake, sporadic movements	<40	0.1	0.3	0.2
12	Awake, constant movements	<40	**	**	**
13	Awake, constant movements	<40	**	**	**
14	Awake, sporadic movements	<40	**	0	**
15	Awake, constant movements	<40	**	**	**
			<b>Mean ±SD: 0.14±0.2 (n= 10)</b>	<b>Mean ±SD: 0.2±0.3 (n=12)</b>	<b>Mean ±SD: 0.3±0.3 (n=10)</b>

\*\* Indicates that the ABR wave I or wave V was not obtainable with one or both of the ABR systems, with the result that latencies could not be determined

The number of successful click-evoked and 0.5 kHz tone burst (TB) recordings using the VS and BL ABR systems is illustrated in Figure 4.8. In general, both ABR systems were more successful with click stimuli than with 0.5 kHz TB stimuli. Assessment of the success rate of the systems individually, showed that more subjects were testable with the VS ABR system than with the BL ABR system.

The VS ABR system was successful in 14/15 and 13/15 subjects using click and 0.5 kHz TB stimuli respectively. In the case of the BL ABR system, it was possible to obtain electrophysiological hearing thresholds for 12/15 subjects (using click stimuli) and for 11/15 subjects (using 0.5 kHz TB stimuli). These findings are illustrated in Figure 4.8.



**Figure 4.8: Successful click-evoked and 0.5 kHz TB ABR recordings using the VS and BL ABR systems**

The VS system was successful in more cases than the BL system using click and 0.5 kHz TB stimuli. However, to determine whether the VS ABR system showed a statistically significant better success rate than the BL system (for click and 0.5 kHz TB stimuli), the Fisher Exact P One Tailed test was used. Although results

showed no statistically significant value for click ( $p=.1121$ ) and 0.5 kHz TB stimuli ( $p=.1648$ ), there is a tendency towards the 95% confidence level in both cases.

The strong tendency towards a statistically significant difference between the VS and BL successful ABR recordings (using click and 0.5 kHz TB stimuli) suggests that the VS ABR system may produce a statistically significant success rate for click as well as for 0.5 kHz TB stimuli, provided a larger sample is tested.

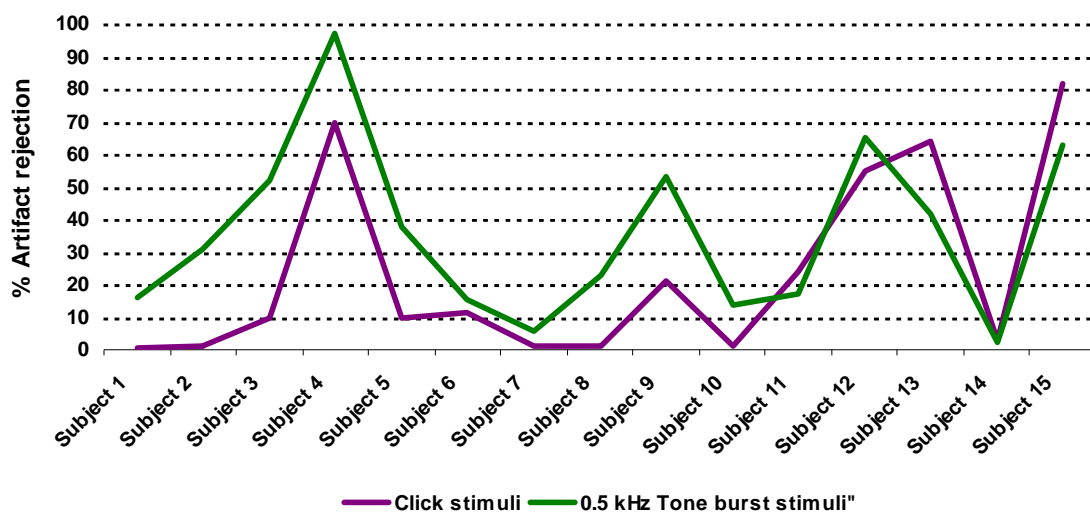
A number of unsuccessful ABR recordings occurred in the study. The cases in which ABR recordings were unsuccessful are presented in Table 4.8. The VS ABR system was unsuccessful in one subject for the click-evoked ABR and in two subjects for the 0.5 kHz TB ABR. The BL ABR system proved successful in three subjects for the click-evoked ABR and in four subjects for the 0.5 kHz tone burst ABR.

**Table 4.8: Subjects with unsuccessful ABR recordings**

Subjects	Type of CP	VS ABR system		BL ABR system	
		Click stimuli	0.5 kHz TB stimuli	Click stimuli	0.5 kHz TB stimuli
3	Microcephaly				X
13	Right hemiplegia			X	X
14	Athetosis		X	X	X
15	Athetosis	X	X	X	X

As shown in Table 4.8 the BL ABR system, using click stimuli, was unsuccessful in Subject 13, Subject 14 and Subject 15, whilst the 0.5 kHz TB BL ABR recordings were inconclusive in Subject 3, Subject 13, Subject 14 and Subject 15. The VS ABR system was unsuccessful in Subject 14 (using 0.5 kHz TB stimuli) and Subject 15 (using 0.5 kHz TB and click stimuli).

Noteworthy was the percentages of artifact rejection by the BL ABR system for three of the four subjects mentioned above. The acceptable percentage of artifact rejection for ABR recordings is an upper limit of 20% (Hall, 2007). The artifact rejection percentage in Subject 3, Subject 12, Subject 13 and Subject 15 exceeded this value in click-evoked and/or 0.5 kHz TB recordings as shown in Figure 4.9. These subjects displayed sporadic involuntary body movements, especially head, neck and jaw movements which probably caused high levels of internal noise.



**Figure 4.9: Percentage of rejected sweeps in the BL ABR system in subjects with unsuccessful ABR recordings using click and 0.5 kHz TB stimuli**

The high percentage of artifact rejection might have contributed to the unsuccessful ABR recordings in Subject 3, Subject 13 and Subject 15. However, the percentage of artifact rejection was well below the acceptable percentage of 20% in Subject 14 (2.68% and 5.93%).

#### **4.3.2 Electrophysiological thresholds of the VS and BL ABR systems using click and 0.5 kHz TB stimuli**

Table 4.9 provides the mean thresholds, standard deviations, and the minimum and maximum thresholds (in dB nHL) for both systems (See Chapter 3 paragraph

3.6.2.4 and Table 3.5 for the calculation of the dB nHL reference values for click and 0.5 kHz TB stimuli for both systems).

The average click-evoked threshold obtained with the VS system was 28 dB nHL with a SD of  $\pm 18$  dB nHL. The large SD consequently leads to a wide range of normal deviation between 10 dB nHL to 46 dB nHL. The mean threshold of the BL system for click stimuli was 21 dB nHL with a SD of  $\pm 14$  dB nHL. The range of normal deviation for the click-evoked thresholds obtained with the BL system was therefore 7 dB nHL to 35 dB nHL.

**Table 4.9: The distribution of the ABR thresholds (dB nHL) of the VS ABR and BL ABR systems using click and 0.5 kHz TB stimuli**

	Sample (N)	Mean	SD	Minimum	Maximum
<b><u>Click stimuli</u></b>					
VS system	14	28	$\pm 18$	7	67
BL system	12	21	$\pm 14$	-1	49
<b><u>0.5 kHz TB stimuli</u></b>					
VS system	13	34	$\pm 15$	17	63
BL system	11	37	$\pm 18$	15	75

The mean 0.5 kHz TB threshold for the VS system was 34 dB nHL with a SD of  $\pm 15$  dB nHL. Hence, the normal range of deviation for the 0.5 kHz TB recording with the VS system was between 19 dB nHL to 53 dB nHL. The average 0.5 kHz tone burst threshold for the BL system was 37 dB nHL with a SD of  $\pm 18$  dB nHL. The large standard deviations obtained with 0.5 kHz TB recordings of the VS and BL ABR systems led to a wide range of normal deviation of between 19 dB nHL to 53 dB nHL and 19 dB nHL to 55 dB nHL respectively.

The thresholds obtained with the VS system were more widely distributed across the intensity scale (minimum = 7 dB nHL; maximum = 67 dB nHL) when



compared to that of the BL system (minimum = -1 dB nHL; maximum = 49 dB nHL). Although the wide range of the ABR thresholds could be responsible for the large standard deviation, the small research sample could also have contributed to the large SD (Stein, Smit, Du Toit & Strasheim, 1998).

The higher mean electrophysiological thresholds obtained with the VS ABR system could be attributed to the fact that the VS ABR system was successful for more subjects than the BL ABR system. Thus, to compare the thresholds of the two systems, only the thresholds of the subjects in which both systems were successful needed to be considered. Table 4.10 presents the mean and SD values for the thresholds that were obtained with both ABR systems.

**Table 4.10: The mean ABR thresholds and SD (dB nHL) of the VS ABR and BL ABR systems using click stimuli (n=12) and 0.5 kHz TB stimuli (n=11)**

	Sample (N)	Mean	SD
<b><u>Click stimuli</u></b>			
VS system	12	25	±16
BL system	12	21	±14
<b><u>0.5 kHz Tone burst stimuli</u></b>			
VS system	11	32	±16
BL system	11	37	±18

#### **4.3.3 Threshold correspondence of the VS and BL ABR systems to behavioural PT thresholds**

The mean difference between the two ABR systems and the behavioural PT thresholds were determined by comparing the click-evoked threshold of each system with the 2 kHz and 4 kHz PT thresholds, and the 0.5 kHz TB ABR threshold of each system with the 0.5 kHz PT threshold. For the results of this section it needs to be considered that ABR stimuli used for the purposes of this

study were calibrated in dB nHL for a group of normal listeners as discussed in Chapter 3 (see paragraph 3.6.2.4 and Table 3.5). The deviation between the click stimuli of both ABR systems did not significantly differ from the 0 dB HL standard for behavioural pure tone thresholds at 2 kHz and 4 kHz as specified by ANSI (S3.6-1996). Thus, the click stimuli thresholds of both systems (in dB nHL) and the behavioural PT thresholds in dB HL are comparable without any significance. The deviation between the 0.5 kHz TB stimuli for both ABR systems was also not significantly different from the 0 dB HL standard for the behavioural PT thresholds at 0.5 kHz as specified by ANSI (S3.6-1996). The 0.5 kHz TB stimuli thresholds (in dB nHL) of both ABR systems were therefore comparable to the 0.5 kHz behavioural PT thresholds (in dB HL) without any significant deviation. As there was no significant difference between the dB nHL intensity scale for the ABR stimuli of both systems and the dB HL intensity scale of the behavioural PT, thresholds were compared in dB HL.

Another important factor was the fact that the consistency of the behavioural PT responses varied from subject to subject. It was mentioned earlier in this chapter (paragraph 4.2.3 and Table 4.6) that 7/15 subjects responded consistently to the PT stimuli (Group A), whilst the behavioural PT thresholds of the remaining 8 subjects were unreliable (Group B). Therefore, for purposes of accuracy, the differences between the ABR systems and the behavioural PT thresholds of Group A are provided individually prior to a presentation of the similar results which include the total sample, i.e. subjects of Group A and subjects of Group B. Furthermore, Subject 13, Subject 14 and Subject 15 were excluded from the calculation of threshold differences between the click-evoked ABR and 2 kHz and 4 kHz PT as the BL ABR procedure was not feasible for any of these subjects. The sample of 15 subjects were also reduced to 11 for determining the mean threshold differences between the 0.5 kHz TB thresholds and the 0.5 kHz PT thresholds, because the BL system proved not feasible for these subjects as well as Subject 3.

The threshold differences for the two ABR systems are individually presented in the subsequent text.

#### **4.3.3.1 Threshold correspondence at 2 kHz, 4 kHz and the average of 2 kHz and 4 kHz**

Click-evoked threshold differences of the VS and BL ABR systems are represented by a normal distribution in Table 4.11.

Differences between the VS and BL ABR systems were apparent for the subjects in the different groups (subjects in Group A and subjects in Group A and B). Table 4.11 illustrates that the VS ABR threshold differences were within 15 dB or less of the behavioural PT thresholds in 6/7 subjects in Group A. For the same group, however, the results of the BL ABR system were slightly different in that the threshold differences were within 20 dB or less of the behavioural PT thresholds in 6/7 subjects. Thus, it seemed that the VS ABR system corresponded better with high frequency PT thresholds (2 kHz, 4 kHz, and the average of 2 kHz and 4 kHz) than the BL ABR system. Upon inclusion of behavioural PT thresholds of subjects in Group B (unreliable behavioural PT thresholds) the BL ABR system illustrated a better correspondence with the behavioural PT than the VS ABR system. As shown in Table 5.8, the BL ABR system threshold differences were within 20 dB or less of the behavioural PT thresholds in 11/12, 10/12 and 10/12 subjects as opposed to 7/12, 8/12 and 8/12 of the subjects tested with the VS ABR system at 2 kHz, 4 kHz and the average of 2 kHz and 4 kHz respectively.

**Table 4.11: Distributions of threshold differences (click-evoked ABR threshold – PT threshold) for the VS and BL ABR systems at 2 kHz, 4 kHz and the average of 2 kHz and 4 kHz**

Threshold difference	VS ABR system						BL ABR system					
	Subjects of Group A (Reliable PT thresholds)			Subjects of Group A and B (Reliable and unreliable PT thresholds)			Subjects of Group A (Reliable PT thresholds)			Subjects of Group A and B (Reliable and unreliable PT thresholds)		
	N=7			N=12			N=7			N=12		
	2kHz	4 kHz	Average 2-4 kHz	2kHz	4 kHz	Average 2-4 kHz	2kHz	4 kHz	Average 2-4 kHz	2kHz	4 kHz	Average 2-4 kHz
Less than or equal to <b>10 dB</b>	4/7	6/7	6/7	6/12	8/12	8/12	4/7	4/7	5/7	8/12	8/12	7/12
Less than or equal to <b>15 dB</b>	6/7	6/7	6/7	7/12	8/12	8/12	4/7	5/7	5/7	8/12	7/12	7/12
Less than or equal to <b>20 dB</b>	6/7	6/7	6/7	7/12	8/12	8/12	6/7	6/7	6/7	11/12	10/12	10/12

In order to determine whether there was a statistically significant difference between the ABR thresholds of each system and the PT thresholds, collective data had to be considered. The collective results for the mean threshold differences of subjects in Group A (n=7) at 2 kHz, 4 kHz and the average of 2 kHz and 4 kHz are presented in Table 4.12, whilst collective results for mean threshold differences for subjects in Group A and Group B (i.e. the total sample) (n=12) are presented in Table 4.13.

**Table 4.12: Mean threshold differences at 2 kHz, 4 kHz and the average for 2 kHz and 4 kHz for subjects in Group A (n=7)**

	Mean threshold difference (mean $\pm$ SD) (dB)	
	VS ABR system	BL ABR system
<b>2 kHz</b>	9 $\pm$ 10	11 $\pm$ 13
<b><i>p-value</i></b>		0.8
<hr/>		
<b>4 kHz</b>	6 $\pm$ 11	8 $\pm$ 13
<b><i>p-value</i></b>		1.0
<hr/>		
<b>Average for 2 kHz and 4 kHz</b>	8 $\pm$ 10	9 $\pm$ 13
<b><i>p-value</i></b>		0.8

The mean threshold differences for the BL ABR system at 2 kHz, 4 kHz and the average of 2 kHz and 4 kHz were 11 dB, 8 dB and 9 dB respectively. The SD of the mean threshold differences remained constant at 2 kHz, 4 kHz and the average of 2 kHz and 4 kHz ( $\pm$ 13 dB). The normal range of deviation for the

threshold differences of the BL ABR system was therefore -2 dB to 24 dB, -5 dB to 21 dB and -4 dB to 22 dB respectively.

**Table 4.13: Mean threshold differences at 2 kHz, 4 kHz and the average of 2 kHz and 4 kHz for subjects in Group A and B sample (n=12)**

	Mean threshold difference (mean $\pm$ SD) (dB)	
	VS ABR system	BL ABR system
2 kHz	13 $\pm$ 12	9 $\pm$ 12
<i>p-value</i>	0.23	
4 kHz	12 $\pm$ 17	9 $\pm$ 1
<i>p-value</i>	0.23	
Average for 2 kHz and 4 kHz	13 $\pm$ 15	9 $\pm$ 13
<i>p-value</i>	0.21	

The mean threshold differences, SD as well as the normal range of deviation, were visibly smaller for the VS ABR system, though statistically the threshold differences at 2 kHz, 4 kHz and the average of 2 kHz and 4 kHz were not significant ( $p=0.8$ ;  $p>0.05$ ) as determined by the Wilcoxon Signed-Rank test. The small sample size ( $n=7$ ) could have contributed to the inconclusive statistical findings. Upon inclusion of the inconsistent behavioural PT thresholds, i.e. for the subjects of Group B ( $n=12$ ), the Wilcoxon Signed-Rank test also indicated no significant difference of threshold differences between the two ABR systems ( $p = 0.21$ ;  $p=0.23$ ;  $p>0.05$ ). Although there was no statistically significant difference, the threshold differences were noticeably larger for the VS ABR system than for the BL ABR system.

In addition to the mean threshold differences and the standard deviations, the range of threshold differences for each ABR system is presented in Table 4.14. Subjects in Group A and the subjects in Group A and B are dealt with separately. From the table it is apparent that the inclusion of the behavioural PT data obtained from subjects in Group B affected the maximum threshold of the ABR systems, in particular the VS system.

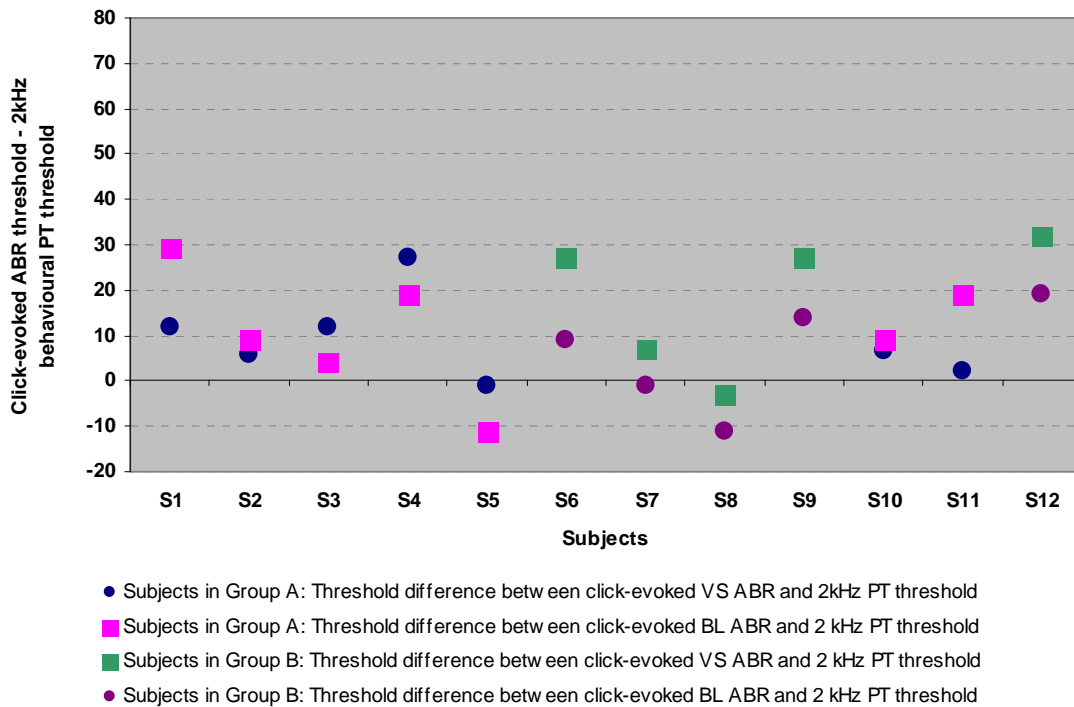
**Table 4.14: Range of threshold differences of ABR systems using click stimuli for subjects in Group A and subjects in Group A and B**

	VS ABR system		BL ABR system	
	Minimum	Maximum	Minimum	Maximum
Difference at 2 kHz (dB nHL)	-1	27	-11	29
	-3	32	-11	19
Difference at 4 kHz dB nHL)	-8	27	-16	24
	4	42	-1	34
Difference at the average of 2 kHz and 4 kHz (dB nHL)	-6	27	-14	27
	-6	37	-9	27

Key: ■ Minimum and maximum threshold differences of subjects in Group A

■ Minimum and maximum threshold differences of subjects in Group A and Group B, i.e. the total sample

Threshold differences for individual subjects were determined for all subjects with comparable thresholds. Figures 4.10, 4.11, and 4.12 illustrate the differences between the click-evoked threshold of each ABR system and the PT thresholds at 2 kHz, 4 kHz and the average for 2 kHz and 4 kHz respectively for each subject. Although the behavioural PT thresholds of all the subjects (n=12) were plotted on the graphs, different colours and symbols were used to distinguish the subjects with reliable behavioural PT thresholds (n=7) from the subjects who responded unreliably to behavioural stimuli (n=5).

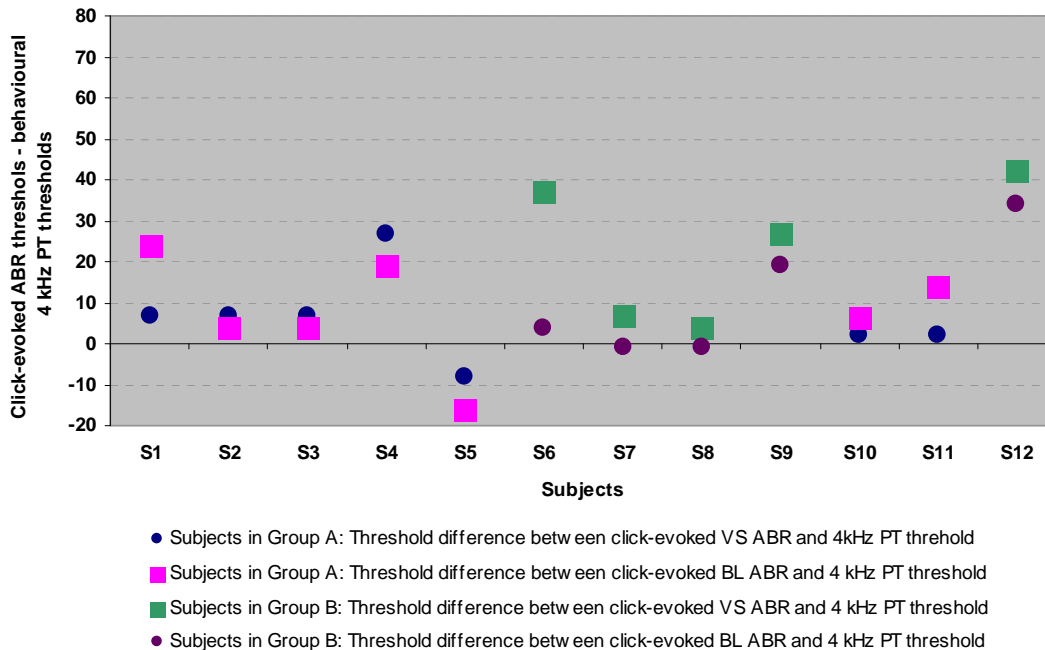


**Figure 4.10: Threshold differences between the click-evoked thresholds (VS and BL ABR systems) and the 2 kHz behavioural PT threshold. Group A - subjects who responded consistently during behavioural PT audiometry; Group B - subjects who responded inconsistently during behavioural PT audiometry.**

Figure 4.10 shows that threshold differences equal to, or less than 10 dB were present in 6 subjects using the VS ABR, compared to 7 subjects using the BL ABR system. Threshold differences between 11 dB to 20 dB were present in two subjects implementing the VS ABR system and four subjects using the BL ABR system. Furthermore, there were a number of subjects with threshold differences equal to or greater than 25 dB between both ABR systems and the 2 kHz PT threshold. In particular, the difference between the click-evoked VS ABR system and the 2 kHz behavioural PT thresholds for Subject 6, Subject 9 and Subject 12 were 27 dB, 27 dB and 32 dB respectively. It must be noted that these subjects responded inconsistently to the PT stimuli. The largest difference between the click-evoked thresholds of the BL ABR system and the 2 kHz PT threshold was



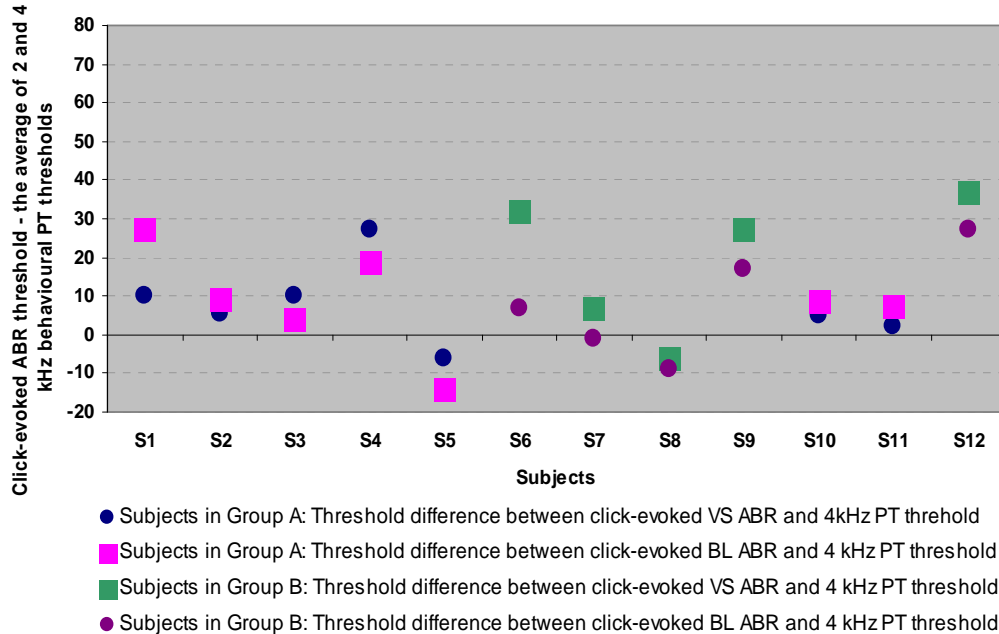
found in Subject 1. This difference was 29 dB whereas the difference between the click-evoked threshold of the VS system and the PT threshold was 12 dB.



**Figure 4.11: Threshold differences between the click-evoked thresholds (VS and BL ABR systems) and the 4 kHz behavioural PT threshold. Group A - subjects who responded consistently during behavioural PT audiometry; Group B - subjects who responded inconsistently during behavioural PT audiometry.**

Results for threshold differences between the click-evoked thresholds of each ABR system and the behavioural PT threshold of the average for 2 kHz and 4 kHz were very similar to the threshold differences at 2 kHz and 4 kHz respectively. Eight subjects presented with a threshold difference equal to, or smaller than 10 dB with the VS and the BL ABR systems. Threshold differences between 11 dB and 25 dB occurred in two subjects using the BL ABR system, whilst differences equal to or larger than 25 dB occurred in four subjects using the VS ABR system and two subjects using the BL ABR system. These results are illustrated in Figure 4.12. The largest threshold differences while using the VS ABR system occurred in Subjects 6 (32 dB), Subject 9 (27 dB) and Subject

12 (37 dB). The largest differences between the thresholds while using the BL ABR system and 4 kHz PT threshold were found in Subject 1 and Subject 12 (both 27 dB).



**Figure 4.12: Threshold differences between the click-evoked thresholds (VS and BL ABR systems) and the average of the 2 kHz and 4 kHz behavioural PT thresholds. Group A - subjects who responded consistently during behavioural PT audiometry; Group B -subjects who responded inconsistently during behavioural PT audiometry)**

#### 4.3.3.2 Threshold correspondence at 0.5 kHz

The mean differences between the 0.5 kHz TB threshold using the VS ABR system and the 0.5 kHz behavioural PT threshold, as well as the 0.5 kHz TB threshold rendered by the BL ABR system and the 0.5 kHz behavioural PT thresholds are presented in this section. As in the case of the 2 kHz and 4 kHz threshold differences, the mean differences of the thresholds of each ABR system and the behavioural PT thresholds of Group A, are presented in isolation followed by the inclusion of the behavioural PT thresholds of the subjects in Group B.

**Table 4.15: Normal distributions of threshold differences (0.5 kHz TB ABR threshold – behavioural PT threshold at 0.5 kHz) for the VS and BL ABR systems at 0.5 kHz**

Threshold difference	VS ABR system		BL ABR system	
	Subjects in Group A (Reliable PT thresholds) (N=6)	Subjects in Group A and B (Reliable and unreliable PT thresholds) (N=11)	Subjects in Group A (Reliable PT thresholds) (N=6)	Subjects in Group A and B (Reliable and unreliable PT thresholds) (N=11)
Less than or equal to <b>30 dB</b>	4/6	7/11	5/6	7/11
Less than or equal to <b>35 dB</b>	5/6	9/11	6/6	9/11
Less than or equal to <b>55 dB</b>	6/6	11/11	6/6	11/11

As illustrated in Table 4.15, TB thresholds were within 30dB or less of the 0.5 kHz behavioural PT threshold for 4/6 and 5/6 (using the VS and BL ABR systems respectively) of the subjects in Group A and 7/11 of subjects in Group A and B. Furthermore, TB thresholds were within 55 dB or less of the 0.5 kHz PT thresholds in all subjects of both groups.

The mean difference for both ABR systems at 0.5 kHz is presented in Table 4.16. The mean difference between the 0.5 kHz tone burst VS ABR thresholds and the 0.5 kHz behavioural PT were similar (26 dB  $\pm$  16 dB) for subjects in Group A and subjects in Group A and B (i.e. the total sample). On average, the BL system presented with a smaller threshold difference (24 dB  $\pm$  6 dB) than the VS ABR system for subjects in Group A. However, when the unreliable behavioural

responses were included, the mean threshold difference (31 dB) was 5 dB larger than the mean threshold difference of the VS ABR system (26 dB). As shown in Table 4.16, the standard deviations were large for both systems, except for the BL system in Group A which presented with a SD of  $\pm 6$  dB. The normal range of deviation was 10 dB to 42 dB for the VS ABR system. The BL system yielded a smaller normal range of deviation for the subjects in Group A (18 dB to 30 dB) than for the subjects of Group A and B (13 dB to 52 dB). The differences for the subjects of Group A, and the subjects of Group A and B were not significant ( $p > 0.05$ ) as determined by the Wilcoxon Signed-Rank Test.

**Table 4.16: Mean threshold differences at 0.5 KHz for subjects in Group A as well as subjects in Group A and B**

	Mean threshold difference (mean $\pm$ SD) (dB)	
	VS ABR system	BL ABR system
Subjects in Group A (n=5)	26 $\pm$ 16	24 $\pm$ 6
<i>p-value</i>		0.26
<hr/>		
Subjects in Group A and B (n=11)	26 $\pm$ 16	31 $\pm$ 18
<i>p-value</i>		0.25

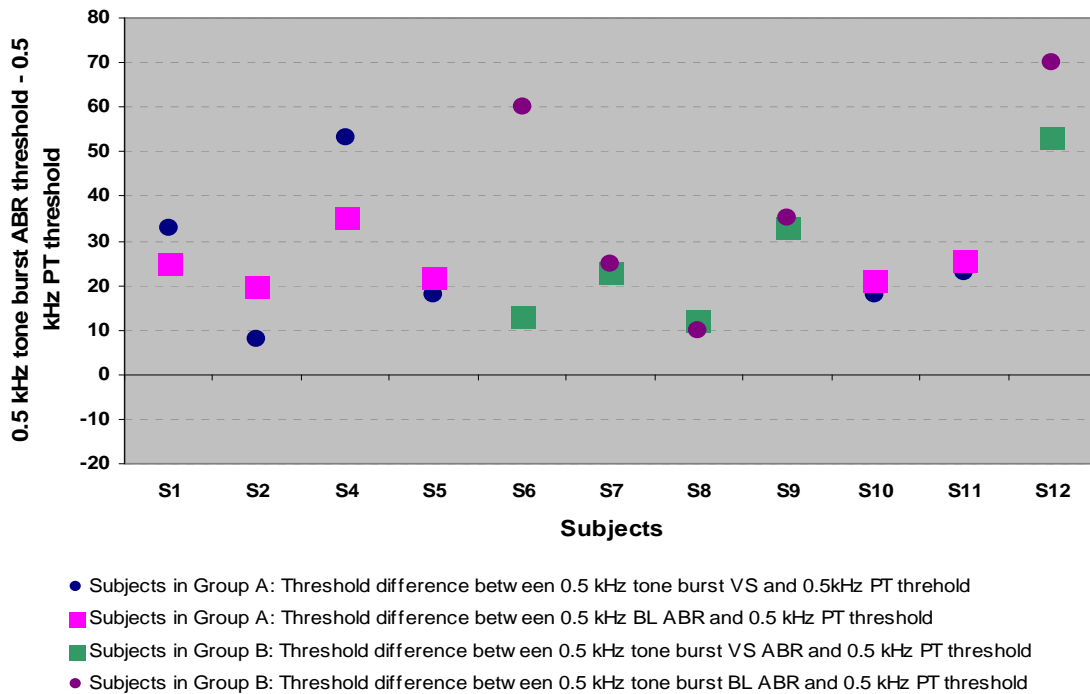
In addition to the mean threshold differences and the standard deviations, the range of threshold differences for each ABR system is presented in Table 4.17. Subjects in Group A and the subjects in Group A and B are dealt with separately. From the table it is apparent that the inclusion of the behavioural PT data obtained from subjects in Group B affected the maximum threshold difference of the ABR systems, in particular the BL system (70 dB).

**Table 4.17: Range of threshold differences of ABR systems using 0.5 kHz TB stimuli for subjects in Group A and subjects in Group A and B**

	VS ABR system		BL ABR system	
	Minimum	Maximum	Minimum	Maximum
Difference at 0.5 kHz (dB)	8	33	20	35
	12	53	10	70

Key: ■ Minimum and Maximum threshold differences of subjects in Group A  
■ Minimum and maximum threshold differences of subjects in Group A and Group B i.e. the total sample

In five subjects (Subjects 5, 7, 8, 10 and 11) both ABR systems rendered a threshold difference of equal to or smaller than 25 dB. The threshold differences obtained with both ABR systems for Subjects 4, 6, 9 and 12 can be seen as outliers. The difference between the 0.5 kHz TB threshold of the VS system and the 0.5 kHz behavioural PT for Subject 4 was 53 dB. The threshold differences indicated by the BL system for Subjects 6 and Subjects 12 were 60 dB and 70 dB respectively. These results are illustrated in Figure 4.13.



**Figure 4.13: Threshold differences between the 0.5 kHz TB thresholds (VS**

and BL systems) and the 0.5 kHz behavioural PT threshold. Group A - subjects who responded consistently during behavioural PT audiometry; Group B - subjects who responded inconsistently during behavioural PT audiometry.

#### 4.3.4 Recording time of the VS and BL ABR systems using click and 0.5 kHz TB stimuli

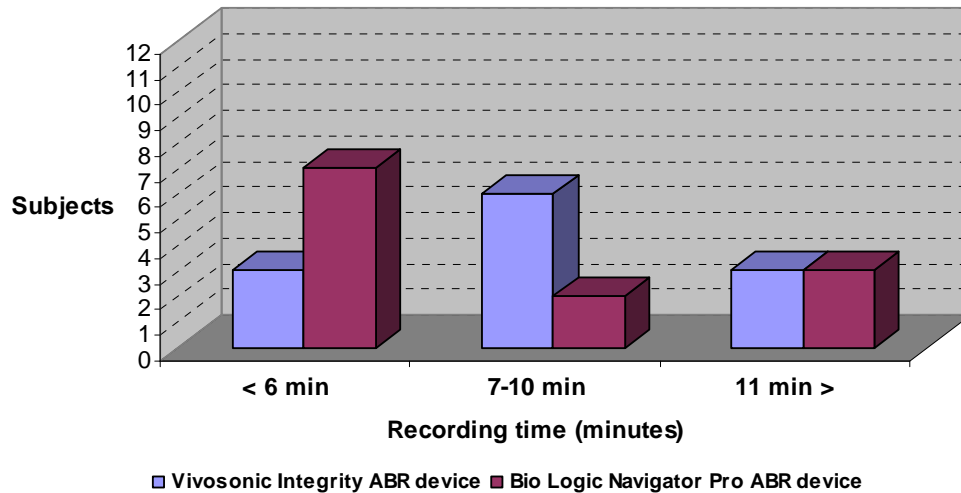
The subjects for whom ABR recordings were unsuccessful – in only one system or both ABR systems – were excluded when the mean recording time per ear was determined. As it was still possible to obtain electrophysiological thresholds for Subjects 3, Subject 13 and Subject 14 using the VS ABR system, the recording times were calculated and are presented in Table 4.18.

**Table 4.18: VS ABR recording time per ear for subjects in whom ABR assessments using the BL ABR device were not successful**

Stimuli	Recording time per ear (minutes)		
	Subject 3	Subject 13	Subject 14
<b>Click</b>	Threshold obtained; therefore included in mean recording time	7	2
<b>0.5 kHz TB</b>	11	6	Threshold was not obtainable (i.e. unsuccessful ABR recording)

The recording time can be defined as the amount of time (in minutes) needed to determine the electrophysiological threshold per ear. The recording time of the ABR measurements was classified into three broad time limits (equal to, or less than 6 minutes, 7 to 10 minutes and equal to, or more than 11 minutes). The number of recordings that was possible in 1 to 6 minutes, 7 to 10 minutes and 11

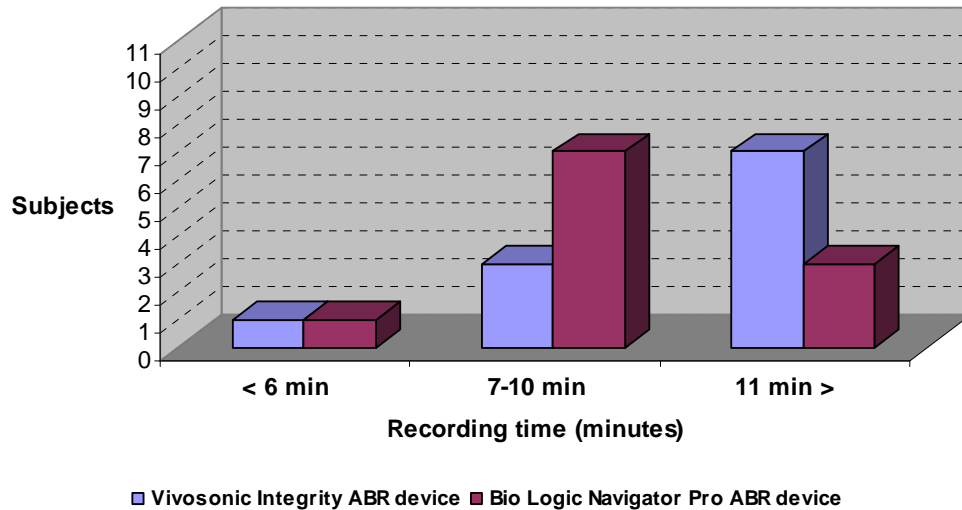
minutes or more is shown Figures 4.14 (click stimuli) and Figure 4.15 (0.5 kHz TB stimuli).



**Figure 4.14: Recording time per ear for VS and BL ABR systems using click stimuli**

Figure 4.14 illustrates the recording time of both systems using the click stimulus. From this figure it is apparent that in 7 subjects ( $n=12$ ) the recording time for one ear was 1 to 6 minutes using the BL ABR system. Contrarily, using the VS ABR device, recordings of 3 subjects ( $n=12$ ) were possible within the same time constraints. Within the 7 to 10 minutes time limit, ABR recordings of 6 subjects and 2 subjects ( $n=12$ ) were administered with the VS system and BL system respectively. In 3 subjects an extended recording time (i.e. 11 minutes or more) was needed for both ABR systems before a threshold was obtained.

For the 0.5 kHz TB recordings it was apparent that both systems required a longer recording time per ear. As shown in Figure 4.15 there was only 1 subject in whom an ABR threshold was obtained in 6 minutes or less with the VS as well as the BL ABR system. Within the 7 to 10 minutes time limit, ABR recordings of 3 subjects and 7 subjects ( $n=11$ ) were administered with the VS and BL ABR systems respectively. An extended recording time (i.e. 11 minutes or more) was required in 7 subjects and 3 subjects for the VS and BL systems respectively before an electrophysiological 0.5 kHz TB threshold was obtained.

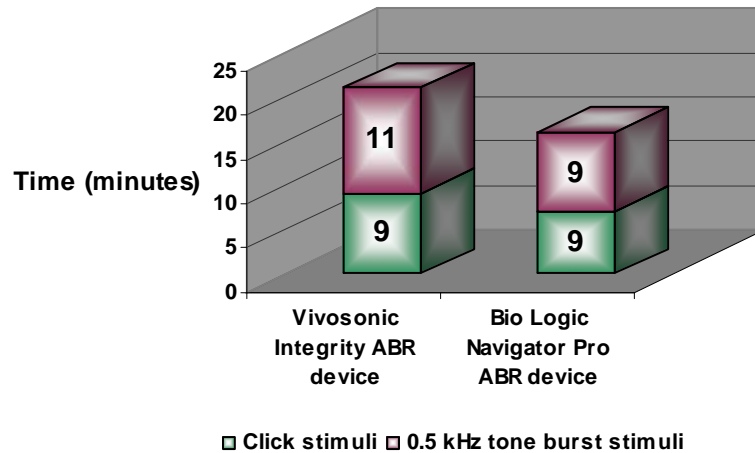


**Figure 4.15: Recording time per ear for VS and BL ABR systems using 0.5 kHz TB stimuli**

The mean and SD recording time per ear was  $9 \pm 4$  minutes for the VS and  $9 \pm 5$  minutes for the BL ABR systems using click stimuli. The normal recording time per ear for click-evoked thresholds therefore ranged between 5 and 13 minutes for the VS ABR system and between 4 and 14 minutes for the BL ABR system.

Using 0.5 kHz TB stimuli, the mean and SD recording time per ear was  $9 \pm 5$  minutes for the BL ABR system. The normal range of deviation for recording 0.5 kHz TB stimuli with the BL ABR system was between 5 and 13 minutes. The mean and SD recording time per ear was  $11 \pm 3$  minutes for the VS ABR system. The normal range of deviation for recording 0.5 kHz TB stimuli with the VS ABR system was between 8 and 14 minutes. The mean recording time per ear for both ABR systems using click and 0.5 kHz TB stimuli is presented in Figure 4.16.





**Figure 4.16: Mean recording time per ear for VS and BL ABR systems using click and 0.5 kHz TB stimuli**

The Wilcoxon Signed-Rank Test was implemented to determine whether there was a statistical difference between the mean recording times of the ABR systems. No significant difference was found between the recording times of the VS and BL ABR system for click stimuli ( $p = 0.13$ ; thus  $p > 0.05$ ). Although the recording times of the VS and BL ABR systems for 0.5 kHz TB stimuli also did not differ significantly, the BL ABR system neared the 90% confidence level of  $p = 0.13$ .

#### 4.4 Conclusion

Each auditory procedure that was conducted yielded its own set of results. The results of the first sub-aim were of a descriptive nature and served to provide information regarding the middle ear functioning, cochlear functioning and hearing sensitivity of each subject. Results of the second sub-aim were to an extent descriptive in nature and, although inferential statistics were used, inconclusive findings were obtained, possibly due to the small research sample.

#### **4.5 Summary**

Chapter 4 presented the results of each auditory procedure that was conducted. As explained in Chapter 3, the results of the empirical research were presented according to the sub-aims. As the first-sub aim focused on the feasibility and characteristics of the procedures within the auditory test battery, the results of the immittance audiometry, DPOAE measurements and behavioural PT audiometry were presented and described. In order to realize the second sub-aim a comparison between the VS and BL ABR systems were made in terms of their feasibility, the correspondence to the 0.5 kHz, 2 kHz, 4 kHz PT thresholds and the recording time per ear.

## Chapter 5

# DISCUSSION

*The aim of this chapter is to introduce the research question, to provide the rationale for the study, to explain the terminology used, and to present an overview of the content and the organization of the study.*

### 5.1 Introduction

Chapters 1 and 2 discussed auditory assessments and its challenges in populations with multiple disabilities, in particular the population with cerebral palsy (CP). The importance of the identification of a hearing loss was emphasized and the difficulty to detect and diagnose the hearing loss, especially in the CP population, was discussed extensively.

Detection and diagnosis of a hearing loss in the CP population is challenging due to the complexity of the condition: it is characterized by a variety of additional disabilities, i.e. physical, cognitive and perceptual disabilities ranging from mild to severe (Donnelly, Parkes, McDowell & Duffy, 2007; Workinger, 2005; Beckung & Hagberg, 2002; Cogher, Savage & Smith, 1992, Newton, 1977). These additional disabilities may mask the presence of a hearing loss in a child with CP and may ultimately lead to erroneous information regarding the auditory system.

Additional disabilities may mask the presence of a hearing loss in such a way that the feasibility of auditory procedures as well as the reliability of the results obtained is compromised (Workinger, 2005; Cogher et al., 2002; McDonald, 1987; Newton, 1977). The reliability of the results obtained from subjective auditory procedures, e.g. behavioural pure tone (PT) audiometry, is especially at risk since the child with CP may respond inconsistently to PT stimuli.

In cases where behavioural responses to PT stimuli are inconsistent, the objective auditory brainstem response (ABR) procedure can be implemented to determine the integrity of the auditory system up to the level of the brainstem level and also for predicting behavioural PT thresholds by using click and frequency-specific stimuli, i.e. tone bursts (TB), respectively (Hall, 2007; Gorga, Johnson, Kaminski, Beauchaine, Garner & Neely, 2006; Folsom & Diefendorf, 1999; Galambos, Hicks & Jo Wilson, 1984).

The ABR is highly valued in the clinical context and has been successfully implemented in difficult-to-test populations such as infants (Hall, 2007; JCIH, 2007; Jiang, Andrew & Wilkinson 2006; Folsom & Diefendorf, 1999). The clinical value of the ABR in difficult-to-test populations not only includes the identification and diagnosis of a hearing loss; its significance also extends to the management and intervention of auditory disorders.

In the current research the auditory functioning of a sample of children with CP was determined using an audiometric test battery. The results of the test battery were provided in Chapter 4 and are discussed in this section. The ABR was conducted on the selected sample of CP children using two different ABR systems, namely the Vivosonic Integrity (VS) ABR system and the Bio Logic Navigator Pro (BL) ABR system.

The rationale for employing different ABR systems was to determine if new features, i.e. Kalman filtering and pre-amplification by the VS ABR system are clinically practical in auditory assessments of this population with. In the following section the results obtained in this study are discussed and compared with existing relevant literature.

## **5.2 Sub-aim 1 discussion: Characteristics and feasibility of an audiological test battery in children with cerebral palsy**

In this section the results obtained from the immittance measurements, OAE measurements as well as behavioural pure tone (PT) audiometry are discussed. Table 5.1 summarizes different procedures conducted by various authors when assessing the auditory functioning in children with multiple disabilities including CP.

### **5.2.1 Immittance measurements**

Immittance measurements, consisting of tympanometry and acoustic reflexes, reveal essential information about the auditory system (Block & Wiley, 1994). In the current study these measurements were performed as part of the test battery and the results are discussed in terms of the feasibility of the procedures as well as characteristics that were noted during its administration.

As shown in Table 5.1, the inclusion of tympanometry was not mentioned in the majority of the research reports (Romero, Mendez, Tello & Torner, 2008; Topolska, Hassmann-Poznańska & Sołowiej, 2002; Sano, Kaga, Kitazumi & Kodama, 2005; Kolker, 2004; Zafeiriou, Andreou & Karasavidou, 2000; Sheykholeslami & Kaga, 1999; Benham-Dunster & Dunster, 1985; Stein, Ozdamar & Schnabel, 1981). It therefore remains unknown whether this procedure was included in the data selection or data collection procedures.



**Table 5.1: Summary of previous assessment procedures employed in difficult-to-test populations**

Author	Research sample	Sample size	Mean age of sample	Subjective auditory procedures		Objective auditory procedures			
				Behavioural audiometry (PTA, VRA, BOA)	Tympanometry	Acoustic reflexes	OAE	AEP	
Stein, Ozdamar & Schnabel (1981)	Developmentally delayed including CP	82	11-14 years		Not known				✓ (Click-evoked ABR)
Benham-Dunster & Dunster, (1985)	Developmentally delayed including CP	164	29-38 years	✓	Not known	✓			✓ (Click-evoked ABR)
Sheykholeslami & Kaga (1999)	Children who suffered neonatal hyperbilirubinemia, 2 of them developed athetotic CP	3	15 years	✓	Not known			✓ (DPOAE and TEOAE)	✓ (Click-evoked ABR)
Palmu, Puhakka, Rahko & Takala (1999)	Infants	58	2 – 11 months			✓			
Zafeiriou, Andreou & Karasavidou (2000)	Children with spastic form of CP	75	6 years		Not known				✓ (Click-evoked ABR)
Kolker (2004)	Children with spastic form of CP	126	1-14 years		Not known				✓ (Click-evoked)



Sano, Kaga, Kitazumi & Kodama (2005)	Various types of CP	6	18.5 years	✓	Not known			✓ (DPOAE)	ABR and CEP) ✓(Click-evoked ABR)
Driscoll, Kei, Bates & McPherson (2002)	Children with various impairments e.g. intellectual and multiple impairments	489	9.6 years			✓		✓ (TEOAE)	
Topolska, Hassmann-Poznańska, Sołowiej (2002)**	Various types of CP	32	Not known			✓	✓	✓(DPOAE)	✓
Romero, Mendez, Tello & Torner (2008)	Children with perinatal encephalopathy including CP	135	Less than 1 year of age		Not known				✓(Click-evoked ABR)
<b>Current study</b>	Various types of CP	15	15.6 years	✓		✓	✓	✓ (DPOAE)	✓(Click-evoked ABR and 0.5 kHz TB ABR)

\*\* The English abstract of this report was used as the original report was only available in Polish

The possible exclusion of tympanometry in previous research is surprising, especially since literature indicates that difficult-to-test populations, including children with CP, display a high risk of middle ear diseases such as otitis media (Driscoll et al., 2002).

It is well appreciated that middle ear diseases may influence the results of nearly all audiometric procedures including behavioural PT audiometry, OAE measurements as well as ABR (Hall, 2007; Palmu, Puhakka, Rahko & Takala, 1999). In an attempt to avoid false audiometric results due to a compromised middle ear functioning, all the subjects in the current study had to comply with the selection criterion of normal middle ear functioning.

Tympanometry was feasible in all the CP subjects of the current research project. Although tympanometry is generally expected to be viable for all patient populations including babies and children with multiple disabilities, a low success rate (74%) was reported for a group of children with developmental and cognitive disabilities (Driscoll et al., 2002; Palmu et al., 1999). It seems that the feasibility of this procedure, although it is an objective procedure, is still dependent on a certain level of cooperation by the patient (e.g. being quiet and accepting a probe in the ear). When the child does not cooperate to this level for various reasons including immaturity (too young) or cognitive disabilities, the feasibility of this procedure may be compromised.

It is satisfying to report that the 100% feasibility rate obtained in the current research can be attributed to the compliant behaviour of the subjects. The formal education that subjects received for at least six years prior to testing as well as the ages of the subjects (12 years to 18 years) suggested a familiarity with instructions, enhancing compliant behaviour and the viability of the procedure.

Tympanometry measurements were followed by ipsilateral acoustic reflexes. Published research report highlight the clinical value of the acoustic reflex in



special populations (Hall & Mueller, 1997; Northern & Gabbard, 1994; Benham-Dunster & Dunster, 1985). In particular, the sensitivity prediction acoustic reflex (SPAR) may be included as a valuable procedure for predicting hearing thresholds in difficult-to-test populations, although there is a risk of overestimating the hearing loss when relying on this procedure (Benham-Dunster & Dunster, 1985).

Although the current study did not use the SPAR to predict hearing thresholds, ipsilateral acoustic reflex testing was done at 0.5 kHz, 1 kHz and 2 kHz. The research sample of the current study was small (n=15), making it difficult to obtain a specific pattern in the resulting acoustic reflexes. It was apparent, however, that the majority of normal acoustic reflexes were elicited from the subjects with spastic CP whilst the majority of absent acoustic reflexes were obtained from subjects with athetoid CP. In the athetoid group there was also one subject (Subject 15) for whom this procedure was not feasible because of consistent muscular movements.

### **5.2.2 Distortion product otoacoustic emissions**

The advantages of OAE measurements, such as its objectivity and brevity, contribute to the wide spread implementation of this procedure especially in the assessment of auditory function in difficult-to-test populations (Driscoll et al., 2004; Longsbury-Martin, McCoy, Whitehead & Martin, 1992). In previous studies an additional advantage of the OAE procedure, namely site of lesion specificity, adds particular value to differential diagnosis of a hearing loss in the CP population (Sano et al., 2005; Sheykholeslami, & Kaga, 1999).

However, in terms of the CP population limited research regarding OAEs is available. The available reports are characterized by small research samples, reducing generalization of the findings within this population. Table 5.2 provides a summary of the available research reports involving the CP population.

**Table 5.2: Summary of OAE research involving the CP population**

Author	Sample size (n)	Sample type	Type of OAE	Results
Sano et al. (2005)	6	Mixed type of CP; Ataxia; Athetosis	DPOAE	Absent OAEs bilaterally in 83% of the subjects; normal in 17%
Topolska et al. (2002) **	Unknown	Unknown	DPOAE	37.5% of children with extrapyramidal CP (i.e. athetoid CP) presented with hearing loss
Sheykholeslami & Kaga (1999)	3	Athetosis	DPOAE and TEOAE	Absent or abnormal OAEs were measured bilaterally in all the subjects
<b>Current research</b>	15	Athetosis Spastic Microcephaly	DPOAE	Absent, abnormal and normal OAEs were measured in 16%, 5% and 79% of the subjects, respectively

\*\* The English abstract of this report was used as the original report was only available in Polish

In contradiction to previous research reports, the majority of the DPOAEs (79%) obtained in the current research were within the normal range as specified by the Vanderbilt criteria. These normal OAE measurements were all obtained from subjects with the spastic form of CP. Interestingly, there was a percentage of normal OAEs (11% and 8% in the left and right ears respectively) that exceeded the amplitude range of the 95<sup>th</sup> percentile of the Vanderbilt criteria, predominantly in the low and mid frequencies (635 Hz to 1586 Hz). Compared to the Vanderbilt 95<sup>th</sup> percentile, the extent of the amplitudes obtained in 6 of the spastic CP subjects (n=10) ranged between 0.1 and 10.95 dB SPL.

Reasons for the increased amplitudes of the DPOAEs in the six subjects with spastic CP remain unclear. Interestingly, research indicated that increased DPOAE amplitudes in the lower frequencies are often displayed in subjects with sickle cell disease (SCD) (Stuart, Jones & Walker, 2006; Downs, Stuart & Holbert, 2000). Additionally, statistically significant associations were revealed between this condition and developmental disabilities such as CP (Ashley-Koch, Murphy, Khoury & Boyle, 2001; Downs et. al., 2000). Although it could not be inferred that the subjects in the current study also presented with SCD, it remains interesting and creates an opportunity for further research.

Previous research conducted within the CP population did not note an increase in the amplitudes of DPOAEs, though reported absent or abnormal OAEs. As shown in Table 5.2, the majority of OAEs recorded in CP subjects in previous studies was either abnormal or absent (Sano et al., 2005; Sheykholeslami & Kaga, 1999). The OAE results obtained in the current study contradicts previous research: in all subjects where OAE-testing was possible (i.e. emissions were reliable and noise levels were low) ( $n=14$ ), only 5% of the OAEs were absent or abnormally reduced.

Absent or abnormally reduced OAEs are usually an indication of malfunctioning of the outer hair cells (OHC) of the cochlea supporting the results of previous studies in terms of the prevalence of a sensorineural hearing loss in children with CP (McDonald, 1987; Newton, 1977; Durrant, 1992; Longsbury-Martin et al., 1992). Despite the findings of these studies, none of the previous reports noted the effects of excessive muscular movements, typically displayed by the CP population, on the OAE measurements.

Excessive muscular movements create high levels of internal noise, thereby creating a high noise floor level during OAE testing. These high noise floor levels affect the signal-to-noise ratio (SNR). Accurate and reliable detection of the OAE relies on an adequate SNR where the level of the noise should not exceed that of

the signal (OAE) (Baer & Hall, 1992). Thus, a high noise floor level will influence the detection of reliable emissions leading to inaccurate results and ultimately to an erroneous conclusion regarding cochlear functioning. Two of the reports listed in Table 5.2 (Sano et al., 2005; Sheykholeslami & Kaga, 1999) indicated a large percentage of absent OAE measurements, but no mention is made of the possible adverse effect of high levels of internal noise typical of patients with CP. Thus, the question can be raised whether the OAEs were absent or abnormal purely due to OHC failure or were the feasibility of the OAE measurements compromised by excessive muscular movements.

As theory states the importance of a low noise level, in the current study the noise levels for each OAE measurement (i.e. for each subject) were taken into account. In Chapter 4 it was reported that the noise floor level was below 3 dB SPL in 14/15 subjects. To be regarded as a DPOAE, the noise floor level should not exceed 3 dB SPL (Hall & Mueller, 1997). There was, however, one subject (Subject 15) in whom the noise floor levels exceeded 3 dB SPL.

Subject 15 was diagnosed with athetoid CP and presented with excessive muscular movements throughout the administration of the OAE measurements. The consistency and excessiveness of the muscular movements produced consistently high noise floor levels which made the reliable detection of the OAE impossible.

Interestingly, Subject 5, Subject 8 and Subject 14 were also diagnosed with the athetoid type of CP and did present with some muscular movements during OAE measurements, but the noise floor levels were consistently below 3 dB SPL. Whilst Subject 5 and Subject 14 presented with absent OAE measurements, OAEs obtained from Subject 8 were within the normal range as specified by the Vanderbilt criteria. The variety of the OAE results in just one sub-group of the sample (the athetoid group) emphasized the variability within the CP population point to the problem of generalizing OAE results in this population.

### 5.2.3 Behavioural pure tone audiometry

Behavioural PT audiometry remains fundamental within the diagnostic audiometric process. However, the administration and ultimately the feasibility of this procedure may become a challenge when confronted with various factors (e.g. age of the individual, the level of formal education, the severity of cognitive, physical or perceptual disabilities) that may reduce the consistency of responding to pure tone stimuli (Workinger, 2005; Folsom & Diefendorf, 1999; Hodgson, 1994; Benham-Dunster & Dunster, 1985).

Considering the various factors that may influence the administration of behavioural PT audiometry, it is not surprising that in the current study the consistency of responses to PT stimuli varied between CP subjects. Although behavioural PT audiometry was feasible in all the subjects, there was a percentage of subjects with athetoid CP (3/5; 60%) and spastic CP (5/10; 50%) that responded inconsistently to the PT stimuli. This was illustrated in Table 4.6.

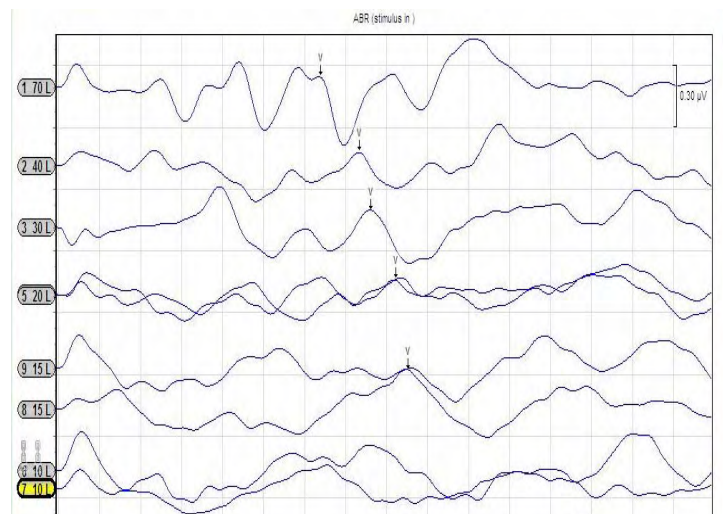
The researcher distinguished between subjects who responded reliably to PT stimuli (Group A) and subjects who responded inconsistently to PT stimuli (Group B). Although this distinction was made, the mean behavioural PT thresholds of the subjects in Group A and Group B were very similar as illustrated in Chapter 4. In the majority of the subjects in Group A and Group B behavioural PT thresholds within the normal range (0d B HL to 20 dB HL) were obtained. Only two subjects (Subject 5 in Group A and Subject 15 in Group B) presented with elevated behavioural PT thresholds (between 40 dB HL to 90 dB HL). Both these subjects showed a ski-slope configuration moderate to severe sensorineural loss. The presence of the sensorineural hearing loss in these subjects, whom were both diagnosed with athetoid CP, correlates with literature that proposes the presence of a sensorineural hearing loss specifically in the athetoid group (Sano et al., 2005; Northern & Downs, 1991; McDonald, 1987, Newton, 1977).

### 5.3. Sub-aim 2 discussion: Comparing the Vivosonic Integrity ABR system with a conventional ABR system

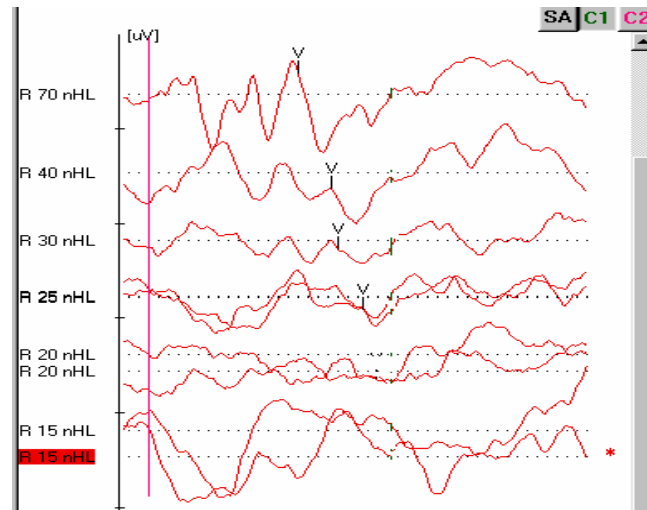
The Vivosonic Integrity ABR system (VS) was compared to an ABR system with conventional technology, in this instance the Bio Logic Navigator Pro system. The VS system was compared to the BL ABR system in terms of the feasibility, the threshold correspondence to behavioural PT thresholds as well as the recording time. The results of each of these comparisons were presented separately in Chapter 4 and are also individually discussed in the following section.

#### 5.3.1 Feasibility of the VS and BL ABR systems using click and 0.5 kHz TB stimuli

The feasibility of the ABR procedure is particularly significant for the identification of a hearing loss or auditory neuropathy in those populations in which behavioural PT thresholds are unreliable or unobtainable (Hall, 2007). Therefore, a high clinical value in terms of the success rate of the click-evoked ABR is essential for assessments of the difficult-to-test populations such as CP. Illustrations of feasible ABR recordings conducted with the VS and BL ABR systems are presented in Figure 5.1 and Figure 5.2 respectively.



**Figure 5.1: An example of a feasible ABR recording using click stimuli with the VS ABR system**



**Figure 5.2: An example of a feasible ABR recording using click stimuli with the BL ABR system**

For the CP population limited research is available that reveals the success rate of ABR assessments. Stein et al. (1981) reported that ABR recordings were successful in 96% of their research sample, whilst Benham-Dunster & Dunster (1985) reported a success rate of 73% to 74% (profoundly delayed subjects) and 89% to 91% (moderately delayed subjects). It is interesting to note that, as shown in Table 5.3, in both these investigations sedation was used during the ABR recording.

The higher success rates of the ABR recording in the previous studies compared to the success rates of the current study may be partially explained by the use of sedation. Sedatives limit muscular movements, thus enhancing the restfulness of the child which is a requirement for an acceptable SNR in that the amplitude of the noise (i.e. myogenic potentials caused by muscular movements) does not exceed the amplitude of the ABR (Hall, 2007). Subjects in the current study were awake and sitting on a chair watching a silent movie.

**Table 5.3: A review of the percentage successful ABR recordings conducted in CP populations**

		Author	Stimuli used in ABR recording	% Successful ABR recordings
<b>Research conducted with sedation</b>		Stein et al. (1981)	Click	<b>96%</b>
		Benham-Dunster & Dunster (1985)	Click	Moderately delayed subjects: <b>89-91%</b> Profoundly delayed subjects: <b>73-74%</b>
<b>Research conducted without sedation</b>	<b>Current research</b>		Click →	VS ABR system: <b>93%</b> BL ABR system: <b>80%</b>
			0.5 kHz TB →	VS ABR system: <b>80%</b> BL ABR system: <b>73%</b>

Although the SNR can effectively be improved by the utilization of sedation or general anaesthesia, CP children display a high risk for developing upper respiratory obstruction e.g. sleep apnea when the sleeping pattern is manipulated (Schmidt, Krief, Deuster, Matulat & Zehnoff-Dinnesen, 2007; Surya, Harkera, Begentb, & Chongc, 2005; Johnson, Page, Williams, Wassemer & Whitehouse, 2002; Sanchez, Zaldivar, Padilla & Morales, 2002; Elwood, Hansen & Seeley, 2001). As the manipulation of the sleeping pattern remains dangerous in the CP population, alternative techniques such as natural sleep or the sleeping agent melatonin may be administered to improve the SNR during ABR recording (Schmidt et al., 2007; Surya et al., 2005).

Whilst research showed that melatonin can be used effectively in children with multiple disabilities (Schmidt et al., 2007), at least one previous study indicated that the ABR can be recorded in CP infants during natural sleep (Romero et al., 2008). Although natural sleep has been used in CP subjects, this technique could be extremely time-consuming within the clinical setting as the audiologist



because the assessment can only commence once the child falls asleep. Another disadvantage of natural sleep is that the presence of involuntary and uncontrollable muscular movements may still occur during natural sleep, implying that this method may be less effective, especially in the population with CP (Surya et al., 2005).

Seeing that the click-evoked and 0.5 kHz TB ABR recordings were feasible in more than 70% in the current study employing the VS and BL ABR systems without the use of sedatives, melatonin or natural sleep, it seems possible to obtain an ABR with CP children while they are awake. Two factors that could have contributed to the high success rates of ABR assessments in the current study include the age of the subjects (12 years to 18 years) and the fact that the subjects have been in a formal educational setting for at least six years and have received additional rehabilitative services. The subjects in the research sample were therefore familiar with the instructions given to them prior to ABR assessments and displayed adequate cooperation. An additional factor – providing entertainment by means of a silent movie – might also have contributed to the success rates of the ABR recordings. By watching the silent movie the subject was kept occupied during the ABR recordings, which possibly served to enhance restfulness of the subject and reduce involuntary movements.

Although the restfulness of the child contributes largely to an acceptable SNR, the appropriate parameter settings, i.e. acquisition parameters of the ABR also add to the improvement of the SNR (Hall, 2007). As discussed in previously, SNR in the CP population may be compromised by the presence of involuntary muscular movements. In an attempt to improve the SNR, acquisition parameters e.g. analysis time, the number of sweeps and filter settings can be modified to obtain improved ABR recordings in the CP population. Table 5.4 illustrates potential modifications of the acquisition parameters in this population.

As depicted in Table 5.4, literature suggests that, in an attempt to improve the SNR, more sweeps are used (i.e. 2000 sweeps instead of 1000 sweeps) and that the recordings be repeated (Hall, 2007). However, the SNR may not effectively be improved by increasing the number of sweeps since unwanted neuromuscular energy still interferes with the ABR signal because it shares a portion of the frequency spectrum of the ABR (Hall, 2007).

**Table 5.4: Potential modifications of the acquisition parameters during ABR assessments in the CP population**

Acquisition parameters usually employed in the ABR protocol (click and tone burst stimuli)	Possible modifications of acquisition parameters specifically for the CP population	Rationale for possible modifications of the acquisition parameters
<p><b>Filter settings</b></p> <p>Low pass filter: 30Hz-100Hz (or 200Hz for click stimuli)</p> <p>High pass filter: 2000Hz-3000Hz</p>	<p>Low pass filter: 100Hz (click and tone burst stimuli)</p>	<p>Neuromuscular activity shares a portion of the ABR frequency. In an attempt to obtain a purer ABR signal a higher low pass filter setting, e.g. 100Hz, is therefore suggested.</p>
<p><b>Analysis time</b></p> <p>10ms to 15ms</p>	<p>15ms to 20ms</p>	<p>Because the child with CP presents with an immature central nervous system (CNS), a longer analysis time may be needed to incorporate all the ABR components.</p>
<p><b>Repetitions/sweeps</b></p>	<p>2 runs of 2000 (at least) OR whatever is needed for a sufficient SNR</p>	<p>Since the child with CP may display excessive muscular movements that will interfere with the ABR recording, more sweeps may be needed in an attempt to obtain an adequate SNR.</p>

Adapted from: Hall (2007)

In an attempt to eliminate some of the redundant myogenic potentials that share a portion of the frequency spectrum of the ABR, the filter settings of ABR systems, in particular the low pass filter can be adjusted. Table 5.4 suggests a low pass filter setting of 100Hz to reduce segments of unwanted myogenic potentials. From Table 5.5, which summarizes ABR research previously conducted with the population with multiple disabilities including CP, it is clear that the majority of the studies, including the current study, used a protocol with a higher low pass filter setting of 100Hz (Romero et al., 2008; Sheykholeslami & Kaga, 1999; Stein et al., 1981).

Table 5.5 also shows that some studies used an even higher low pass filter of 150Hz and 200Hz (Zafeiriou, Andreou & Karasavidou, 2000; Benham-Dunster & Dunster, 1985). Although low cut filter settings of 150Hz to 300Hz are still acceptable for click-evoked ABR recordings since this type of stimulus display a broad spectral frequency, Hall (2007) cautions against excessive filtering. Excessive filtering may not only result in the elimination of important portions of the ABR, but may also contribute to the formation of a distortion product in the waveform which can be falsely identified as a response component (Hall, 2007).

In the current study excessive filtering of low frequency energy might have contributed to the lower success rates obtained with both systems utilizing 0.5 kHz TB stimuli. Literature clearly states that TB stimuli are dominated mainly by low frequency energy (Hall, 2007). This implies that the use of a low pass filter such as 30 Hz is more appropriate since it encompasses the low frequency energy of the TB stimulus. On the other hand, using a higher low pass filter setting, e.g. 100Hz, the risk of eliminating essential components of the TB ABR is increased. Hence, it could be argued that the using the 100Hz low pass filter for the 0.5 kHz TB recordings could have been a drawback in the current study. However, as stated in the previous chapters, the rationale for using this particular low pass filter setting was an attempt to obtain 0.5 kHz TB recordings even in the

presence of neuromuscular movements typically encountered in the CP population without sedation.

The audiologist consequently faces a challenge when conducting frequency-specific ABR recordings in the CP population in that an increase in the low pass filter setting may filter out some of the large myogenic potentials, but at the same time may be responsible for unreliable recordings of the ABR (Hall, 2007). This dilemma may explain the lack of research specifically using tone burst stimuli in populations with multiple disabilities. However, the importance of incorporating frequency-specific ABR recordings remains critical for the diagnostic audiology process since intervention services, i.e. the fitting of hearing aids for children with CP, highly depend on it.

Although the majority of the VS and BL ABR assessments in the present study were successful (as discussed in the previous text), there was a number of subjects in whom click-evoked and 0.5 kHz TB recordings were unsuccessful as illustrated in Table 4.8.

Unsuccessful ABR recordings suggest that the ABR components (i.e. wave I, wave III, wave V) are not identifiable nor repeatable (Hall, 2007). Unsuccessful ABR recordings may be attributed to various factors including the presence of a profound sensory hearing loss or conditions of a compromised central nervous system (CNS), such as auditory neuropathy (Hall, 2007; Topolska et al., 2002; Rance et al., 1999). Furthermore, additional symptoms of a compromised CNS, e.g. excessive involuntary and uncontrollable muscular movement, may also affect the feasibility of the recording of the ABR because excessive muscular movements may be responsible for large myogenic potentials which directly influence the ABR recording negatively (Hall, 2007). The recording is negatively affected when the amplitude of the myogenic potentials exceeds the amplitude of the underlying ABR signal which may result in an undesirable SNR.



**Table 5.5: A summary of different ABR systems and parameters implemented in previous studies in populations with multiple disabilities**

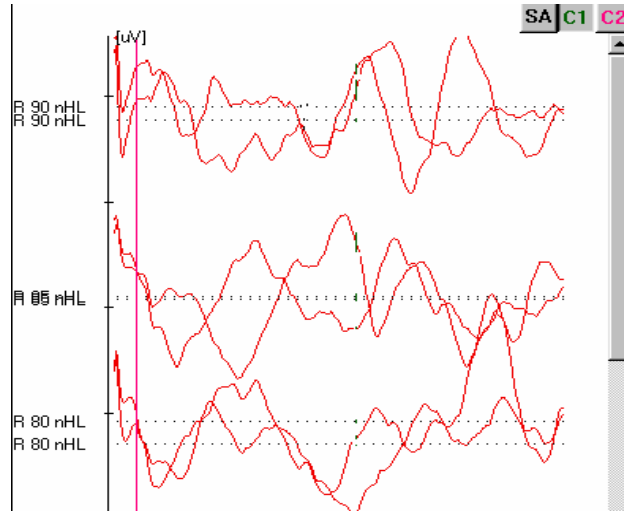
Author	ABR system	Sedation/ general anaesthesia	Acquisition parameters			Stimulus parameters		
			Filter settings	Repetitions (Sweeps)	Analysis time	Type	Polarity	Rate
Stein, Ozdamar & Schnabel (1981)	1 <sup>st</sup> Phase: Grason-Stadler 471-1	Yes	1 <sup>st</sup> Phase: 100- 3000Hz	2048	1 <sup>st</sup> Phase:50ms	Click	Rarefaction	1 <sup>st</sup> Phase: 20.sec
	2 <sup>nd</sup> Phase: Nicolet model 1074		2 <sup>nd</sup> Phase: 100- 3000Hz		2 <sup>nd</sup> Phase: 20ms			2 <sup>nd</sup> Phase: 20/sec
	3 <sup>rd</sup> Phase: Grason Stadler 1216A		3 <sup>rd</sup> Phase: 100- 2000Hz		3 <sup>rd</sup> Phase: 20ms			3 <sup>rd</sup> Phase: Varied between 10- 33/sec
Benham- Dunster & Dunster, (1985)	Nicolet CA 1000	Yes	150-3000Hz	2000	10ms	Click	Rarefaction	19.1/sec
Sheykholesl ami & Kaga (1999)	Neuropack System	Not known	100-3000Hz	Not known	Not known	Click	Rarefaction	Not known
Zafeiriou, Andreou & Karasavidou (2000)	Nihon-Kohden Neurpack 4 system	Not known	200-2000Hz	1024	Not known	Click	Rarefaction	10/sec



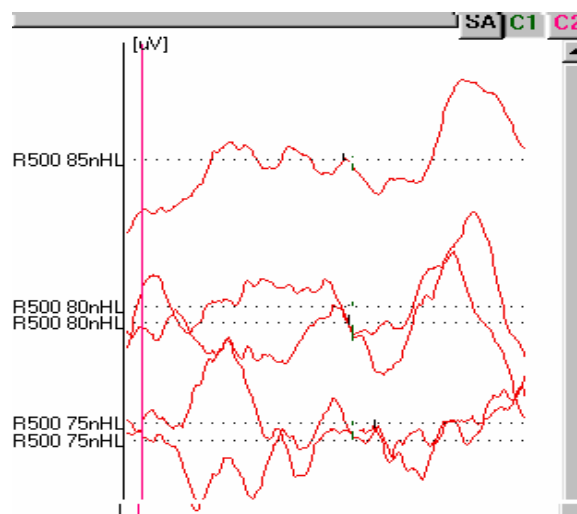
Kolker (2004)	Not known	Not known	50-100Hz	1000	10ms	Click	Rarefaction	20/sec
Sano, Kaga, Kitazumi & Kodama (2005)	Nihon-Kohden Neuropack System	Not known	Not known	Not known	Not known	Click	Not known	Not known
Romero, Mendez, Tello & Torner (2008)	Amplaid MK 15	No - subjects tested during natural sleep	100-2500Hz	2000	15ms	Click	Rarefaction and condensation	11/sec

<b>Current study</b>	<b>Two systems:</b> 1. <b>Vivosonic Integrity</b> 2. <b>Bio Logic Navigator Pro</b>	<b>Both systems:</b> No - subjects awake	<b>Both systems:</b> 100-3000Hz	<b>VS system:</b> 2000-4000 sweeps recording (click and 0.5 kHz TB) <b>BL system:</b> 2 recordings of 2000 sweeps (click and 0.5 kHz TB)	<b>Both systems:</b> Click ABR : 15ms 0.5 kHz TB ABR: 21.2ms	<b>Both systems:</b> : Click and 0.5 kHz TB	<b>Both systems:</b> Click: Rarefaction 0.5 kHz TB: Alternating	<b>Both systems:</b> Click and 0.5 kHz TB: 37.7/sec
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A poor SNR may ultimately influence the feasibility of the ABR (Hall, 2007). Figure 5.3 and Figure 5.4 provide examples of unsuccessful ABR recordings in the current research, implementing the VS and the BL ABR systems.

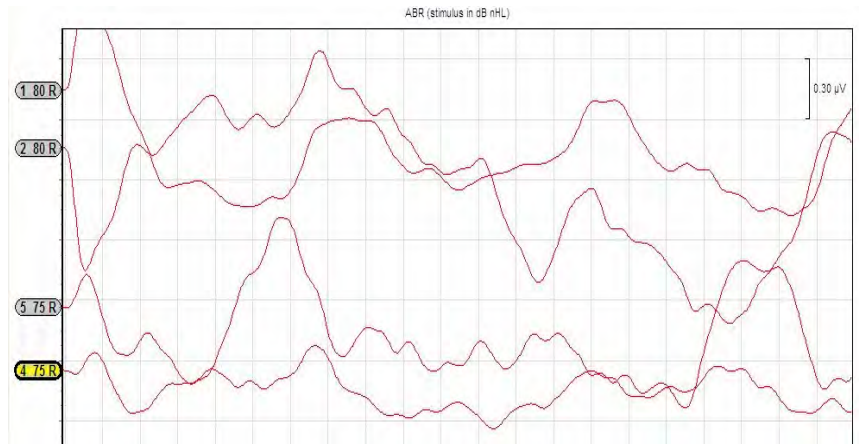


(a)

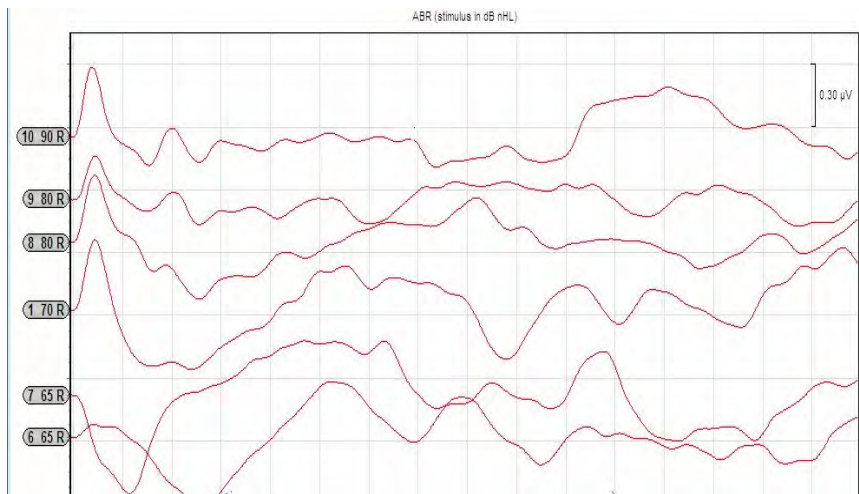


(b)

**Figure 5.3: An example of an unsuccessful ABR recording using click stimuli (a) and 0.5 kHz TB stimuli (b) with the BL ABR system**



(a)



(b)

**Figure 5.4: An example of an unsuccessful ABR recording using click stimuli (a) and 0.5 kHz TB stimuli (b) with the VS ABR system**

In this investigation the VS ABR system illustrated the highest rate of successful ABR recordings using click and 0.5 kHz TB stimuli. This is noteworthy when considering that both ABR systems were exposed to similar test conditions and were employed simultaneously. Thus, it could be argued that the novel features of the VS ABR system, i.e. pre-amplification and Kalman filtering, contributed to ABR components (e.g. wave V) being more readily identifiable in the presence of a poor SNR.



As previously discussed (Chapter 2), the SNR should be improved because pre-amplification holds the promise of reducing the permeation of unwanted myogenic potentials prior to the amplification process, whereas Kalman filtering attempts to reduce the effects of sporadic noise during the ABR recording (Hall, 2007; Steinmann & Kurtz, 2005).

Although the BL ABR system was less successful in more subjects, the implementation of the artifact rejection technique in the present study rendered valuable information. As seen in Chapter 4 (Figure 4.10) there were a number of subjects in whom a high artifact rejection percentage occurred. However, only one subject (Subject 15) and three subjects (Subject 3, Subject 13 and Subject 15) displayed unsuccessful recordings when using click and 0.5 kHz TB stimuli respectively. Click-evoked and 0.5 kHz TB thresholds were therefore obtained from the remaining subjects who also presented with high artifact rejection percentages.

Although excessive muscular movements might have contributed to the some of the recordings being unsuccessful, this is not true for Subject 14. Recordings with both ABR systems indicated absent wave components in the presence of minimal artifacts as illustrated by the percentage of artifact rejection obtained with the BL ABR system (2.68% during click-evoked recordings and 5.93% during 0.5 kHz TB recordings). Subject 14 also presented with absent ipsilateral acoustic reflexes and DPOAEs bilaterally, yet the behavioural PT thresholds were within the normal range. Although it could be argued that this subject might have displayed clinical symptoms of auditory neuropathy spectrum disorder (ANSO) based upon audiological findings, the fact that the subject acquired spoken language and is an effective communicator reduces the likelihood of the presence of this condition (Rance, Beer, Cone-Wesson, Shepherd, Dowell, King, Rickards, Clark, (1999).

### **5.3.2 Electrophysiological thresholds of the VS and BL ABR systems using click and 0.5 kHz TB stimuli**

As previously discussed, behavioural PT thresholds are often not obtainable or might be unreliable in difficult-to-test populations such as CP. Hence,

obtaining reliable electrophysiological thresholds remains essential in the diagnostic audiometric process.

Surprisingly, literature offers limited available data that includes the actual ABR thresholds in populations with multiple disabilities such as CP (Sano et al., 2005; Sheykolsami & Kaga, 2000 Benham-Dunster & Dunster, 1985; Stein et al., 1981). Table 5.6 provides a summary of studies in which ABR results were provided. However, the ABR results were presented differently in the various reports, making comparison of the results difficult.

**Table 5.6: Summary of ABR results in previous studies**

Author	How ABR results were presented	Results
Sano et al. (2005)	ABR thresholds presented in dB nHL	<b>No response at 95 dB nHL</b> (maximum of the ABR)
Sheykholeslami & Kaga (2000)	ABR thresholds presented in dB nHL	<b>No response at 95 dB nHL</b> (maximum of the ABR)
Benham-Dunster & Dunster (1985)	ABR thresholds presented in dB nHL	Moderately delayed subjects presented with a mean ABR threshold of <b>33.9 dB nHL</b> Profoundly delayed subjects presented with a mean ABR threshold of <b>38.9 dB nHL</b>
Stein et al. (1981)	ABR thresholds presented according to diagnostic categories (0-30 dB HL and 40-70dB HL)	43% of the subjects illustrated with hearing sensitivity between <b>0-30dB HL</b> 19.5% of the subjects presented with hearing sensitivity between <b>40-70dB HL</b>
<b>Current research</b>	ABR thresholds presented according to intensity level (dB nHL)	Mean click-evoked ABR threshold of VS system: <b>25 dB nHL</b> (Calculated for 12 Subjects) Mean click-evoked ABR threshold of BL

system:

**21 dB nHL** (Calculated for 12 Subjects)

Mean 0.5kHz ABR threshold of VS

system:

**32 dB nHL** (Calculated for 11 Subjects)

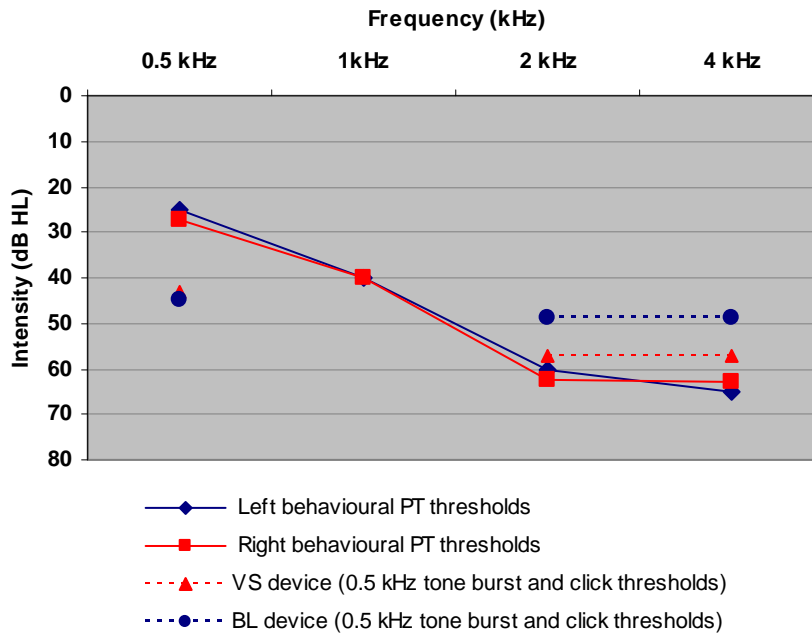
Mean 0.5kHz ABR threshold of BL

system:

**37dB nHL** (Calculated for 11 Subjects)

As depicted in Table 5.6, the ABR thresholds presented in available research reports are diverse. The diversity is, however, not surprising as the heterogeneity of the CP population suggests that the presence of a hearing loss may vary greatly between individuals (Workinger, 2005; Cogher et al., 2002). The results of the current study also showed variability in the ABR thresholds as measured by the VS and BL ABR systems.

When investigating the ABR results of Subject 5, and comparing the electrophysiological thresholds of both systems to the behavioural PT thresholds presented in Figure 5.5, it becomes evident that the click-evoked thresholds of both ABR systems actually underestimated the high frequency hearing loss. This disagreement between the click-evoked ABR thresholds and the behavioural PT thresholds may, however, be expected in the presence of a steeply sloping high frequency hearing loss as in the case of Subject 5 (Hall, 2007; Gorga, Johnson, Kaminski, Beauchaine, Garner, Neely, 2006).



**Figure 5.5: Illustration of the behavioural PT thresholds and ABR thresholds obtained (VS and BL ABR systems) obtained in Subject 5**

Obtaining TB thresholds is imperative during ABR recordings of the difficult-to-test population. However, the identification of the TB thresholds might be challenging in difficult-to-test populations such as CP because the excessive muscular movements often displayed in this population could cause an undesirable SNR (Hall, 2007). The implementation of a higher low pass filter setting (e.g. 100 Hz) in an attempt to account for the undesirable SNR may hinder the identification of the ABR wave V of the TB recording even more.

In the current research project it was also apparent that it was more difficult to identify the ABR wave V when using 0.5 kHz TB stimuli than when using click stimuli. As depicted in Table 5.6, 0.5 kHz TB ABR thresholds were obtained at higher intensities than those of the click-evoked recordings. In fact, there is a 7 dB and 16 dB average difference between the 0.5 kHz TB thresholds and the click-evoked thresholds of the VS and BL ABR systems respectively.

By investigating the 0.5 kHz TB thresholds of each ABR system, it was clear that, contrary to the results of the click-evoked ABR recordings, the VS ABR

system displayed a higher percentage of electrophysiological thresholds that fell within the normal hearing level range than the BL ABR system.

### **5.3.3 Threshold correspondence of the VS and BL ABR systems to behavioural pure tones**

The main aim of the ABR measurements in difficult-to-test populations is to provide estimated behavioural PT thresholds (Hall, 2007; Gorga et al., 2006; Gorga et al., 1993; Picton, 1991). Thus, the difference between ABR thresholds and the behavioural PT thresholds provides an indication of the proximity of the electrophysiological thresholds to the gold standard of behavioural audiometry thresholds.

In the current study, the difference between the electrophysiological thresholds of both ABR systems and the behavioural PT thresholds (0.5 kHz, 2 kHz, 4 kHz, the average of 2k Hz and 4 kHz) provided an indication of how accurate each ABR system estimated hearing sensitivity. These results were reported in the previous chapter and are discussed below.

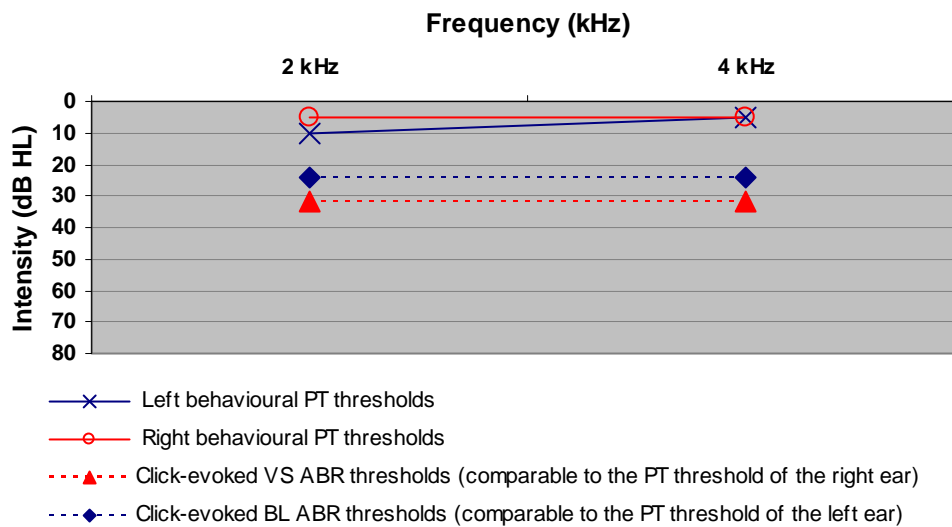
The reliability of the behavioural PT thresholds was important in the determination of the threshold differences. The reliability of these thresholds for some subjects were questionable, therefore the subjects who responded reliably during behavioural PT audiometry (Group A) were distinguished from the subjects who responded inconsistently to the stimuli (Group B). Furthermore, threshold differences of subjects in Group A, and threshold differences of the total sample (subjects in Group A and B) were compared to the pure tone thresholds separately. As reported in Chapter 4, Group A and Group B consisted of 7/15 and 8/15 subjects respectively.

#### **5.3.3.1 Threshold correspondence at 2 kHz, 4 kHz and the average of 2 kHz and 4 kHz**

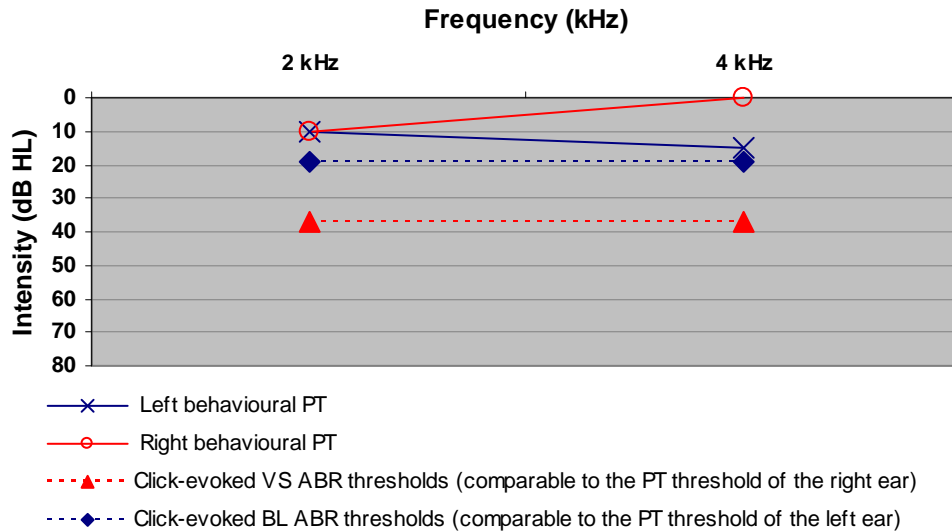
In the current study the mean click-evoked threshold differences for both ABR systems (subjects in Group A and the total sample i.e. subjects in Group A and B) corresponded with findings reported in the literature. Hall (2007) reported an average range of agreement of 5 dB to 15 dB between click-

evoked ABR thresholds and that of the behavioural PT thresholds at 2 kHz and 4 kHz whilst Hood (1995) reported similar ranges (6 dB to 20 dB) for normal hearing subjects between click-evoked ABR thresholds and the behavioural thresholds at 2 kHz and 4 kHz. Although the threshold differences seem to be within a broad range as specified by literature, the large range of threshold differences may provide an indication that both systems are less consistent during ABR recordings in the CP population.

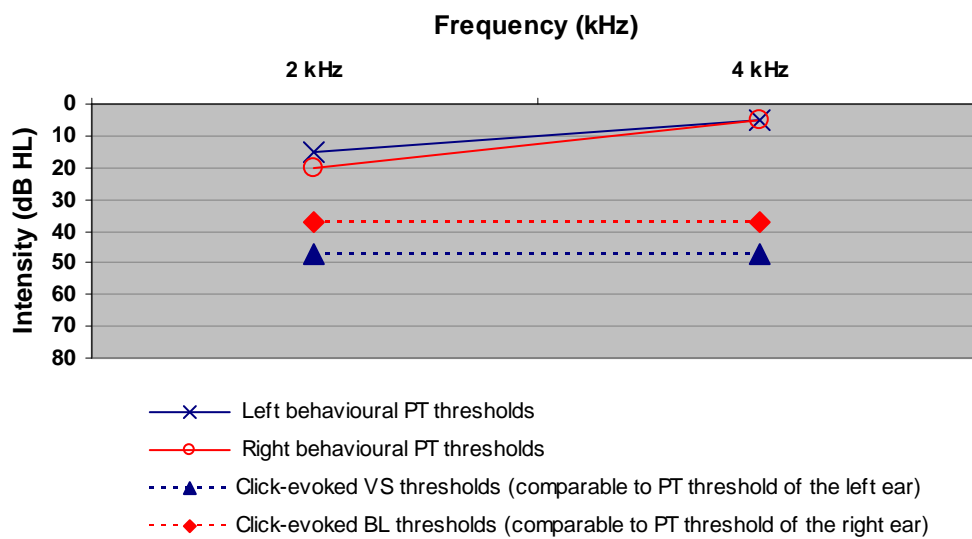
In particular, the inclusion of the inconsistent PT data affected the range of the threshold differences for both systems. Although the range of the threshold differences was also large for subjects in Group A, the range of particularly the VS ABR system increased upon including the PT data of subjects in Group B. This may be attributed to the elevated click-evoked VS ABR thresholds obtained in mainly three subjects (Subject 6, Subject 9 and Subject 12). Figure 5.6, Figure 5.7 and Figure 5.8 clearly show that in all but one of these subjects (Subject 12) the click-evoked thresholds of the VS ABR system exceeded 20 dB.



**Figure 5.6: Behavioural PT thresholds (2 kHz and 4 kHz) and click-evoked thresholds (VS and BL ABR systems) obtained in Subject 9**



**Figure 5.7: Behavioural PT thresholds (2 kHz and 4 kHz) and click-evoked thresholds (VS and BL ABR systems) obtained in Subject 6**



**Figure 5.8: Behavioural PT thresholds (2 kHz and 4 kHz) and click-evoked thresholds (VS and BL ABR systems) obtained in Subject 12**

### 5.3.3.2 Threshold correspondence at 0.5 kHz

As there is a need in diagnostic audiometry to provide PT threshold estimates for frequencies other than 2 kHz and 4 kHz, the use of frequency-specific ABR recordings can be seen as inevitable (Hall, 2007; Gorga et al., 2006). Although several techniques have been implemented to obtain frequency-specificity, research indicated that TB stimuli can be used to predict the magnitude as well as the configuration of a hearing loss reliably (Hall, 2007; Gorga et al., 2006; Purdy & Abbas, 2002; Stapells, 2000).

In the current research 0.5 kHz TB stimuli were used to obtain information regarding low frequency hearing (e.g. at 0.5 kHz) in a CP sample. Although there are currently no research reports available of ABR recordings using TB stimuli in the CP population, literature indicates that the 0.5 kHz TB thresholds are generally within 10 dB to 30 dB of the behavioural PT threshold at 0.5 kHz (Stapell, 2000; Stapells et al., 1995; Hall, 1992; Stapells et al., 1990).

The results of the current study indicated that the mean threshold differences for the VS and BL ABR systems for subjects in both groups (subjects in Group A as well as subjects in Group A and B) were within a broad range of normality as specified by relevant literature (Stapells, 2000; Stapells et al., 1995; Hall, 1992; Stapells et al., 1990). However, a large range of threshold differences obtained with both system may indicate that the variability of the ABR using 0.5 kHz TB stimuli in this population.

The range of threshold differences was particular influenced by large individual threshold differences obtained from Subject 4, Subject 6 and Subject 12. Interestingly, Subject 4, Subject 6 and Subject 12 were all diagnosed with a spastic form of CP. Whilst Subject 4 was diagnosed with quadriplegia, Subject 6 and Subject 12 presented with right hemiplegia and triplegia respectively. Taking into account that Subject 4 and Subject 12 displayed high artifact rejection level in BL ABR recordings of 70% and 97% (click and 0.5 kHz TB stimuli) and 55% and 65% (click and 0.5 kHz TB stimuli) respectively as illustrated in Chapter 4 (Figure 4.10), it could be argued that the severity of the sporadic spasms and/or reflexes displayed in



these subjects contributed to a poor SNR which ultimately challenged the identification of the ABR wave V at lower intensities, i.e. near the actual behavioural PT threshold. This may imply that the threshold differences obtained from both the ABR systems could probably have been smaller than the ones reported in this study.

As in the case of the click-evoked ABR, it could be argued that the incorporation of a cost-effective and relatively safe sleeping agent such as melatonin could improve the SNR. The improvement of the SNR could ultimately lead to a better correspondence between the 0.5 kHz TB ABR and the 0.5 kHz behavioural PT threshold.

#### **5.3.4 Recording time of the VS and BL ABR systems using click and 0.5 kHz TB stimuli**

When conducting a hearing test the general aim is to obtain as much information as possible in the shortest possible time. Together with the feasibility rate of the ABR system and the correspondence to behavioural PT thresholds, the recording time of the ABR provides an indication of the usefulness of this procedure when assessing difficult-to-test populations such as children with CP (Gorga et al., 2006; Bachmann & Hall, 2001).

In the current study the VS and BL ABR system were simultaneously conducted in each subject. This suggests that the recording times for each ABR system obtained were valid for only one ear. As reported in Chapter 4, the recording times per ear for the two ABR systems did not differ significantly: a mean recording time for a click-evoked ABR recording was 9 minutes per ear for both ABR systems, whilst the 0.5 kHz TB mean recording time was 9 minutes and 11 minutes per ear using the BL and VS ABR systems respectively.

Although the fact that recording times were only obtainable from one ear could be seen as a drawback in this study, the results may provide some useful information. Recording time of one ear can provide an indication of the projected recording time for the ABR assessment of both ears. Additionally, as showed in Table 5.7, this projected recording time can provide an

indication of the time frame in which an ABR protocol, using the VS and BL ABR system, might be completed specifically in the CP population.

**Table 5.7: The actual and suggested recording time for VS and BL ABR systems using click and 0.5 kHz TB stimuli**

	Click stimuli		0.5 kHz TB stimuli		ABR protocol using click and 0.5 kHz TB stimuli
	Recording time (1 ear)	Suggested recording time for both ears	Recording time (1 ear)	Suggested recording time for both ears	Suggested recording time (both ears)
<b>VS ABR</b>	9 minutes	18 minutes	11 minutes	22 minutes	<b>40 minutes</b>
<b>BL ABR</b>	9 minutes	18 minutes	9 minutes	18 minutes	<b>36 minutes</b>

The administration of an ABR protocol i.e. a click-evoked recording and a frequency-specific TB recording remains imperative in diagnostic audiology. Thus, the time needed for the ABR protocol to be completed needs to be taken into consideration. As shown in Table 5.7, the projected time for completing the ABR protocol is 40 minutes and 36 minutes using the VS and BL ABR systems respectively.

It is clear that the ABR protocol using the BL ABR system favours the protocol using the VS ABR system by 4 minutes. The 4 minute delay originates from the extended recording time obtained during 0.5 kHz TB recordings. An explanation for the slightly better recording time obtained from the BL system when using the 0.5 kHz TB stimuli might relate to the inclusion of artifact rejection. It might be argued that the inclusion of artifact rejection ensured that the appropriate SNR was achieved faster in comparison to the implementation of Kalman filtering used by the VS system. Kalman filtering attempts to compensate for the contaminated sweeps by waiting until the subject was restful before continuing with the averaging process (Kurtz &

Steinman, 2005). The averaging process of the VS system might have been prolonged because few sporadic moments occurred during the ABR recording where the subjects did not display muscular movements.

The presence of excessive muscular movements may directly have an effect on the recording time of the ABR. Although it seems that artifact rejection might be slightly more effective in terms of time efficiency when using 0.5 kHz TB stimuli, the detrimental effects this process has on the morphology of the ABR needs to be considered. It could be argued that, the only way to effectively reduce the recording time of the ABR assessment, yet maintain clinical validity, is to ensure that an appropriate SNR is sustained throughout the recording. Within a difficult-to-test population such as CP the only way to sustain an appropriate SNR might be when excessive muscular movements are reduced by using a light sedative such as melatonin (Schmidt, Krief, Deuster, Matulat & Zehnoff-Dinnesen, 2007).

#### **5.4 Conclusion**

In this chapter the results of the two sub-aims were discussed separately. The discussion of the results of Sub-aim 1 aimed to provide a general view regarding the feasibility and characteristics of immittance, DPOAEs and behavioural PT audiometry. The uniqueness and the complexity of CP were emphasized through the variability of the results, not only between the subjects, but also when compared to previous research. The variability of results is in accordance with the heterogeneity of the CP condition and stressed the importance of conducting a diagnostic audiological test battery whilst taking into account the uniqueness of each child being assessed.

The discussion of sub-aim 2 was directed towards comparing the VS ABR system to an ABR system with conventional technology (the BL ABR system) in terms of its feasibility, threshold correspondence and recording time when assessing auditory functioning in children with CP. Table 5.8 provides a short summary of the conclusions based on the results obtained. Throughout the discussion it was apparent that the size of the research sample affected the results. The results of the threshold correspondence were further

compromised because the consistency of the subjects' responses to PT stimuli was taken into account and on that basis the sample was divided into two groups.

## **5.5 Summary**

Chapter 5 provided a critical discussion of the results of the current research in the light of existing literature. The results of the auditory procedures that were conducted were discussed separately. Implications for future research were indicated throughout the discussion and the limitations of the current and previous research projects were identified.

## Chapter 6

# CONCLUSIONS AND RECOMMENDATIONS

*The aim of this chapter is to infer general conclusions and implications from the research, to critically evaluate the findings and make recommendations for future research*

### 6.1 Introduction

The main aim of this research project was to determine the clinical utility of the Vivosonic Intergrity (VS) auditory brainstem response (ABR) system in children with cerebral palsy (CP). The results obtained were presented and discussed in the previous chapters. Chapter 6 serves as the closing of the report. Conclusions drawn from the reported results are presented in this chapter and the research process is critically reviewed. Furthermore, recommendations and implications for further research are presented in this chapter.

### 6.2 Conclusions

The research process described in this report was primarily aimed at determining the clinical usefulness of the VS ABR system when assessing auditory functioning in the CP population. In order to realize the main aim various procedures in the audiological test battery were administered on each CP subject followed by simultaneous ABR measurements using the VS system as well as a conventional ABR system. Throughout the research it was apparent that the small sample size influenced the results of the research project. For this reason significant differences by means of inferential statistics between the ABR systems could not be determined.

Conclusions drawn from this project can be divided into two main sections, namely audiological tests in children with CP and ABR assessments in the CP population using the VS ABR system. Conclusions within each section are presented accordingly.

### **6.2.1 Audiological tests in children with cerebral palsy**

- ❑ The variability of the audiological test battery results – between the subjects and when compared to previous research – emphasized the heterogeneity of the CP population. This variability also stressed the importance of evaluating each CP child’s auditory status carefully with a battery of tests to cross-check findings and to identify a hearing loss or an auditory dysfunction such as auditory neuropathy spectrum disorder (ANSD) appropriately.
- ❑ The severity of the physical impairment and of any additional impairments such as mental retardation may influence the consistency and therefore also the feasibility of behavioural pure tone (PT) audiometry. This was apparent since eight subjects (n=15) responded inconsistently to behavioural PT stimuli. The inconsistent behavioural PT data also stressed the necessity for including frequency-specific ABR assessments when determining auditory functioning in children with CP.
- ❑ Underlying conditions such as sickle cell disease (SCD) may be present in children with CP (Ashley-Koch, Murphy, Khoury & Boyle, 2001). Such co-occurring conditions may affect the results of specifically distortion product otoacoustic emissions (DPOAEs).

### **6.2.2 ABR assessments in the CP population using the Vivosonic Integrity system**

- ❑ Higher success rates obtained with the VS ABR system may suggest that this system was feasible in a wider variety of subjects using click as well as 0.5 kHz TB stimuli. The findings of the current research showed that the VS ABR system illustrated high success rates of ABR recordings using click and 0.5 kHz TB stimuli within a small CP sample which consisted of subjects with

spastic CP, athetoid CP as well as microcephaly. Success rates obtained with the VS ABR system were higher than those obtained with the BL ABR system (80% and 73% utilizing click and 0.5 kHz TB respectively).

- ❑ Technology employed in the VS ABR system (Kalman filtering) and the BL ABR system (artifact rejection) may both be useful methods of limiting noise such as myogenic potentials during an ABR recording. This conclusion may be founded on the results obtained in this research that threshold differences between the two ABR systems were not significant ( $p>0.05$ ). Threshold differences obtained with the VS ABR system and the BL ABR system to behavioural PT thresholds at 2 kHz, 4 kHz and 0.5 kHz fell within a broad range of normality as indicated by literature (click-evoked thresholds: within 5 dB to 15 dB; 0.5 kHz TB thresholds: within 10 dB to 30 dB; Hall, 2007; Hood, 1998; Stapells, 2000; Stapells et al., 1995; Hall, 1992).
- ❑ The large range of threshold differences obtained may suggest increased variability of both ABR systems to provide reliable PT estimates within the CP population. Although the threshold correspondence results did not offer significant findings, the range of threshold differences was used in an attempt to provide a better indication of the consistency of the systems. It was clear that both ABR systems displayed a large range of differences between electrophysiological click-evoked thresholds and behavioural PT thresholds (i.e. at 2 kHz, 4 kHz and the average of 2 kHz and 4 kHz the threshold differences of the VS system ranged between -1 dB and 32 dB, 2 dB and 42 dB and between -6 dB and 37 dB respectively whilst threshold differences of the BL system varied between -1 dB and 34 dB, -11 dB and 29 dB and between -14 dB and 27 dB at 2 kHz, 4 kHz and the average of 2 kHz and 4 kHz respectively).
- ❑ The recording time per ear of the VS and BL ABR systems was not significantly different ( $p> 0.05$ ), suggesting that both systems worked reasonably well. Although the recording time per ear of the VS and BL ABR systems was not significantly different, the projected recording time for an ABR protocol, i.e. click-evoked and 0.5 kHz TB recordings, favours the BL

ABR system by 4 minutes. This could imply that the artifact rejection process achieved the appropriate SNR within a shorter period compared to the Kalman filtering method. As Kalman filtering attempts to compensate for the contaminated sweeps by waiting until the subject was restful before continuing with the averaging process, it could be suggested that the averaging process of the VS system might have been prolonged because few sporadic movements occurred during the ABR recording where the subjects did not display muscular movements (Kurtz & Steinman, 2005).

### **6.3 Implications of the findings**

The success rates obtained with both systems suggest that ABR recordings using click- as well as TB stimuli might be more readily conducted in the CP population. The success rates obtained with the BL ABR system (80% and 73% utilizing click and 0.5 kHz TB stimuli respectively) in particular might suggest that the inclusion of artifact rejection remains a reasonably efficient tool to improve SNR during ABR recording, though it was applicable in less individual cases as illustrated by the higher success rates of the VS ABR system.

The high success rates of click-evoked and 0.5 kHz TB recordings attained with the VS ABR system without the use of any form of sedation have various implications in terms of the application of the ABR on different test populations. Since ABR recordings were successful without the use of sedation in a subject sample characterized by excessive muscular movements, it implies that the VS ABR may also be applicable and feasible in other difficult-to-test populations such as infants. Furthermore, the fact that the recordings were conducted in awake and alert subjects suggests that the VS ABR system might be useful in infants who are awake, sleeping or being breastfed. It could be concluded that on quiet awake subjects, including infants, ABR assessments may successfully be recorded using the VS ABR system. Thus, this system may be applicable for screening programs.



The large range of threshold differences that were obtained with the VS ABR system (click: -8 dB to 42 dB; 0.5 kHz TB: 8 dB to 53 dB) and BL ABR system (click: -16 dB to 34 dB; 0.5 kHz TB: 20 dB to 70 dB) may suggest less consistency using both ABR systems. This may imply that, regardless of the technology used (e.g. Kalman filtering or artifact rejection) diagnostic ABR assessments, i.e. determining electrophysiological thresholds, remain challenging within the CP population. Determining ABR thresholds within this population may be regarded as a challenge due to the presence of various symptoms of central nervous system dysfunction most notably of which are inconsistent muscular movements that may cause large myogenic potentials during the ABR recording.

As there were subjects in whom ABR recordings were not feasible with the VS and BL ABR systems, and/or subjects in whom the threshold differences obtained with both systems were large (i.e. 42 dB) it could be argued that both artifact rejection and Kalman filtering only partly improved the SNR during the ABR recordings. This implies that, in order to effectively improve the SNR, CP children need to remain in a relaxed and calm state displaying minimal muscular movements. As CP children have limited or no control over muscular movements, a 'relaxed and calm state' might only be obtained by the utilization of a light sedative (Workinger, 2005; Mechem, 2002; Cogher et al., 2001). A light sedative for ABR assessments in the CP population might be found in the form of melatonin. Research indicates that melatonin poses minimal risks to children with multiple disabilities including CP (Schmidt, Krief, Deuster, Matulat & Zehnoff-Dinnesen, 2007).

Improving the SNR by implementing a patient management technique, i.e. using a light sedative, may directly assist the audiologist in obtaining closer estimates of ABR thresholds to the behavioural PT thresholds. Furthermore, it may also reduce the recording time per ear which may add to the usefulness of ABR assessments in general within the CP population.

#### 6.4 Critical evaluation of the study

In this section the procedures and protocols used in the study are critically evaluated according to their strengths and limitations.

The following **strengths** of this study have been identified:

- The administration of a diagnostic audiometric battery can be seen as a strength of this study. The variety of measurements for auditory functioning assisted the researcher in a comparison of the results. Additionally, it emphasized the importance of the cross-check principle particularly in children with CP.
- A within-subject condition was used for evaluating both ABR systems simultaneously. This meant that both systems were exposed to similar test conditions in terms of muscular activity (EEG) and environmental noise during the testing.
- The fact that TB stimuli were used during ABR recordings can also be seen as a strong point of the study. There are currently no research reports that reveal information regarding ABR recordings using TB stimuli in children with CP. The inclusion of TB stimuli can be seen as an integral part of the ABR assessment because frequency-specific estimates of PT thresholds provide a comprehensive picture of the audiogram.
- Within the current study ABR recordings were conducted without the use of sedatives. This could be identified as an additional strength since ABR recordings in previous research were conducted with the use of sedatives. However, because children with multiple disabilities illustrate a high risk for airway obstruction during sedation or during natural sleep, sedatives was avoided in this study (Schmidt, et al., 2007; Elwood, Hansen, Seely, 2001; Benham-Dunster & Dunster, 1985; Stein et al., 1981).

The following **limitations** of the study have been identified:

- Because of the small sample size ( $n=15$ ), in-depth categorization of certain sets of data, e.g. ipsilateral acoustic reflexes and DPOAEs, was not possible.

Furthermore, the size of the research sample affected the inferential part of the statistics which influenced the second sub-aim of the project, which was to compare the VS ABR system to a conventional ABR system. Although there were some tendencies towards a 95% confidence level for some aspects such as the feasibility of the systems, it was not possible to determine significant differences between the VS ABR and BL ABR systems.

- ❑ The administration of the VS and BL ABR systems simultaneously could also be seen as a limitation of the study. As previously explained, this set-up was necessary to ensure similar test conditions when conducting ABR recordings using different systems. However, this set-up also caused that the electrophysiological thresholds obtained with the different ABR systems could not be directly compared to each other since they were recorded from different ears in the same subject. As a result the electrophysiological thresholds were compared indirectly to each other in terms of the threshold correspondences to behavioural PT thresholds. The comparison between the two ABR systems in terms of the threshold correspondences to behavioural PT thresholds were further complicated as some of the subjects (n=7) responded inconsistently to PT stimuli.
- ❑ The use of a 100 Hz low pass filter during testing could be seen as a limitation of the study as this setting might have affected 0.5 kHz TB recordings of both ABR systems. It is well known that TB recordings depend on low frequency energy (Hall, 2007). The use of a high low pass filter setting such as 100 Hz therefore may compromise recordings to such an extent that elevated electrophysiological thresholds are obtained (Hall, 2007).
- ❑ The use of TB stimuli at only one frequency could be seen as a further limitation of the study. Frequency-specific ABR recording at 1 kHz, 2 kHz and 4 kHz may provide valuable insight not only in terms of the configuration of hearing loss in the CP population, but may also improve the rehabilitative services rendered in this population, such as fitting and verifying hearing aids.
- ❑ Another limitation of the study was that click-evoked recordings were recorded using rarefaction polarity only. Using a condensation polarity

recording after a rarefaction polarity could not only have increased the reliability of the presence of the ABR thresholds, but it could also have indicated subjects with possible auditory neuropathy spectrum disorder (ANSD) by means of the presence of the cochlear microphonic.

## 6.5 Recommendations for further research

- ❑ The presence of increased DPOAE amplitudes in the CP population needs to be investigated. Within the current sample 6 out of 10 subjects with spastic CP presented with enlarged DPOAE amplitudes mainly in the lower and mid frequencies (635 Hz – 1586 Hz). Although a possible relationship between SCD and CP in these subjects has been mentioned, it remains purely speculative. Further research needs to be conducted to determine the prevalence of increased amplitudes in the various sub-groups of CP, i.e. spastic CP, mixed CP and athetoid CP. Future research projects could also focus on the amplitudes of subjects with CP in different age-groups comparing it to control groups of similar ages. Additionally, research could be directed towards the presence of DPOAE as well as the amplitudes of the DPOAE of CP children with confirmed SCD.
- ❑ The current study could be replicated, but with a larger research sample than in the current study where only 15 subjects were included. Increasing the size of the research sample may contribute to more significant values obtained with inferential statistics, which may lead to more specific findings.
- ❑ As mentioned earlier, the simultaneous administration of the two ABR systems caused that the ABR thresholds could not be directly compared to each other. Developing a method of directly comparing electrophysiological thresholds of the two ABR systems in the same ear therefore seems necessary. This could be achieved by monitoring the EEG during each ABR recording and ensuring that the average EEG is comparable when two successive measurements are obtained in the same ear at the same frequency with the two ABR systems.

- ❑ ABR recordings using the VS ABR system should be conducted on CP infants with and without the use of sedation. This type of study may involve high expenditures as trained personnel will need to be incorporated while conducting the ABR with sedation on the CP infant. However, completing a project like this and proving that the VS ABR system can be administrated with success without the use of sedation or general anaesthesia on this population could be significant since it may enhance the applicability of the VS ABR system.
- ❑ Tone burst ABR recordings at 1 kHz, 2 kHz and 4 kHz need to be conducted in the CP population. Currently there are no reports available which focused on TB recordings in this population. Considering that frequency-specific ABR thresholds are needed to provide optimal rehabilitative services such as verifying hearing aids, TB recordings remain imperative in a population which display a higher risk for hearing loss (Hall, 2007; Sano et al., 2005; Topolska et. al., 2002; Sheykhholeslami & Kaga, 1999; McDonald, 1987; Newton, 1977).
- ❑ Since the CP population may display a high risk for ANSD, the prevalence of ANSD needs to be investigated by the implementation of a diagnostic audiological protocol (Shapiro, 2003). Research indicated that the presence of ANSD can be determined by a battery of tests including DPOAEs, acoustic reflexes as well as ABR assessments. In the latter, the presence of a cochlear microphonic within a certain time period remains deterministic for the diagnosis of ANSD, yet is not well researched within the CP population ().

## **6.6 Final conclusion**

The CP condition is a universal phenomenon (Andersen, 2008; Donnely et al., 2007; Fawke, 2007; Couper, 2005; Winter, Autry, Boyle & Yeargin-Allsopp, 2002; Arens & Molteno, 1989). As this vulnerable population also presents with a higher risk for a hearing loss, the audiologist in South Africa is not only in need of sufficient knowledge and clinical skills, but also need audiometric and electrophysiological equipment to assess auditory functioning effectively and efficiently.

The variability of the audiological test battery results obtained in the current research emphasizes the heterogeneity of the CP population and stresses the importance of evaluating each CP child's auditory status carefully with a battery of tests to cross-check findings. However, behavioural PT audiometry, which is regarded as the gold standard of audiometry, is not always viable or reliable in this population (Folsom & Diefendorf, 1999). Thus, the ABR remains an integral part of the auditory test battery for timeous identification of a hearing loss.

Within the current study the VS and BL ABR systems illustrated high success rates during click-evoked and 0.5 kHz TB evoked recording. However, the VS ABR system was successful across a wider range of subjects during click-evoked and 0.5 kHz TB recordings, which may increase its clinical usefulness, especially in terms of hearing screening in the CP population. It seemed that excessive muscular movements during the recordings influenced not only the VS ABR's, but also the BL ABR's threshold correspondences to PT thresholds as well as the recording time of the measurements. Hence, it appears that the use of a light sedative to reduce excessive muscular movements may still be necessary to increase the clinical usefulness of the VS ABR system in the CP population in general.

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