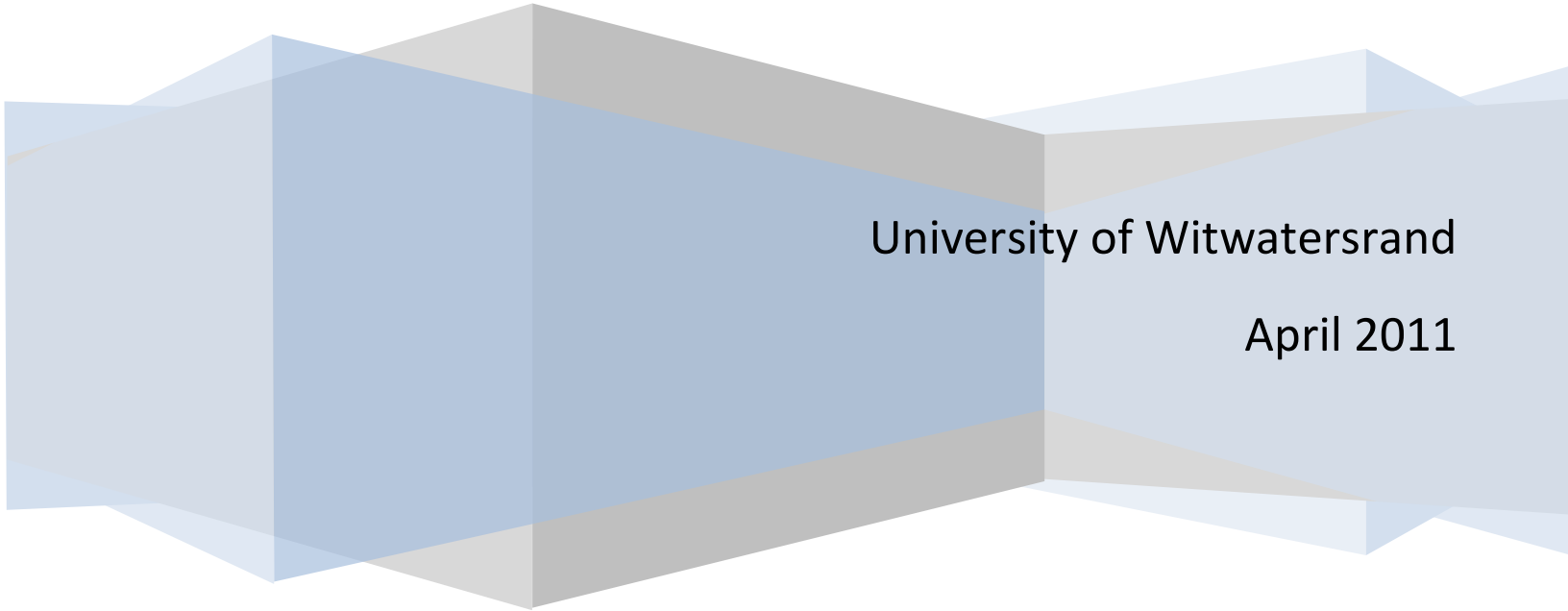
Hearing Loss in the Closed Head Injured Population of South Africa Two to Five Years Post Head Injury

A research report submitted for the degree of Masters of Audiology in the Faculty of Humanities

NATALIE PLAKS



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DEPARTMENT OF SPEECH PATHOLOGY AND AUDIOLOGY

HEARING LOSS IN THE CLOSED HEAD INJURED POPULATION OF SOUTH AFRICA, TWO TO FIVE YEARS POST CLOSED HEAD INJURY

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A RESEARCH REPORT SUBMITTED FOR THE DEGREE OF MASTERS OF AUDIOLOGY IN THE FACULTY OF HUMANITIES

THE UNIVERSITY OF THE WITWATERSRAND

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DECLARATION

I, Natalie Plaks, hereby declare that this submission is my own original work and that the assistance which I have received is detailed in the acknowledgements of this report. To the best of my knowledge and belief this submission contains no material which has been accepted for the award of any other degree or diploma at any other university or other institute of higher learning, except where due acknowledgement has been made in the text. I am responsible for the study and conclusions reached.

NATALIE PLAKS

Date

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LIST OF ABBREVIATIONS

CHI	Closed Head Injury
GCS	Glasgow Coma Scale
SOL	Site of Lesion
MRI	Magnetic Resonance Imaging
CAT	Computerized Axial Tomography
dB	Decibels
PTA	Pure Tone Average
SRT	Speech Reception Threshold
MCL	Most Comfortable Loudness Level
TD/UCL	Threshold of Discomfort/Uncomfortable Loudness Level
OAE	Otoacoustic Emissions
DPOAE	Distortion Product Otoacoustic Emissions
TEOAE	Transient Evoked Otoacoustic Emissions
ABR	Auditory Brainstem Response
AWL	Absolute Wave Latency
IWL	Interwave Latency

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CHAPTER 1: INTRODUCTION AND LITERATURE REVIEW

The aim of this chapter is to present theoretical information which will provide the background rationale for conducting the current study. It will explain closed head injuries (CHI) and describe its effects on one's physical and cognitive well being. It will provide statistics and display the need for audiological evaluations within the CHI population.

1.1 CLOSED HEAD INJURY

The brain is a complex organ, and a person that is diagnosed with a brain injury does not experience all physical and mental impairments associated with such an injury. Depending on where the brain insult occurred, the person demonstrates an altered mental state such as emotional disturbances and/or personality changes in addition to physical and/or mental disabilities (Brown, Malec, Diehl, Englander & Cifu, 2007). Each head injured person's disability is unique and should be treated as such (Brown et al., 2007). It should be noted that in terms of these disabilities a head injured person will most probably demonstrate intellectual and emotional disabilities. In addition, depending where the head insult occurred they might demonstrate sight, hearing, communication and physical disabilities (Brown et al., 2007).

Head injury is a devastating condition that causes major psychosocial complications and requires a multidisciplinary approach for treatment to be effective (Brown et al., 2007). Brown et al. (2007) define an acquired head injury as the acute impairment of normal brain function that causes altered cognitive functioning and includes both open and closed head injuries.

A closed head injury (CHI) is defined as an assault to the brain, resulting from a blow to the head, or from a sudden, violent motion that results in the brain knocking against the skull, causing a physical injury to the living brain tissue (Bergemalm, 2003; Marshall, Sadler & Bowers, 1981).

CHI is a substantial cause of morbidity world-wide (Heitger, Jones, Dalrymple-Alford, Frampton, Ardagh & Anderson, 2006). In a meta-analysis of the incidence of CHI between 1960 and the late 1980's, Naugle (1990) reported an incidence of 200/100 000. Around 80% of those admitted for head injuries are classified as mild, with 100 to 300 cases per year, per 100,000 population (Heitger et al., 2006). Statistics received from a study in Sweden conducted by Bergemalm and Borg (2001), reported that 25,000 to 40,000 individuals acquire head injuries each year. Jennett and McMillan (1981) recorded a yearly head-injury occurrence rate of 17.8/1,000 inhabitants in Scotland. A study in the United States conducted by Brown et al. (2007), reported that approximately 43,000 people suffer head injuries annually. Odebode, Ademola-Popoola, Ojo and Ayanniyi (2005) reported that 200 to 300 people per 100,000 per year in developing countries are reported to have sustained a head injury. An estimate of 89 000 cases of new traumatic brain injuries are reported annually in South Africa (Statistics South Africa, 2010).

1.1.1 Types of CHI

Collinson et al. (2009) report four types of CHI namely: i) a concussion which is considered to be a mild CHI as it temporarily affects the normal brain functioning but there is no loss of consciousness. Even though it is a mild CHI, a concussion leads to symptoms such as headaches, dizziness, nausea, ringing in the ears, slurred speech and vomiting. In some cases the

person has difficulty balancing, and in some cases the symptoms emerge only hours or days later, resulting in secondary symptoms such as mood swings, sensitivity to light and noise and change in sleep patterns; ii) a brain contusion which is a bruise to the brain which may lead to a hemorrhage; if blood is absorbed into the cerebrospinal fluid it can cause permanent neurological damage. Brain contusions are present in 20 to 30 percent of severe CHI where the person may feel weak and numb, loose coordination, struggle with memory or have cognitive difficulties; iii) a Diffuse axonal injury causes permanent damage to the nerves in the brain, severe diffuse axonal injuries lead to vegetative states and comas in 90% of cases; and iv) an intracranial hematoma occurs when the brain strikes the inside of the skull causing blood to pool outside the brain or between the skull and the brain, resulting in unconsciousness, seizures and/or lethargy (Collinson et al., 2009).

It is postulated that a CHI can either be focal, diffuse or a combination of both (Bergemalm, 2003). Focal damage as a result of a CHI implies that the damage occurs in one area of the brain and is usually the result of the head physically striking an object. The damage to the skull is often visible to the naked eye (Granacher, 2007). Focal injuries could result in brain contusion, cerebral laceration, subdural hemorrhage, intracranial hemorrhage, and intraventricular hemorrhage (Collinson, Meyyappan, & Rosenfeld, 2009; Granacher, 2007). With brain contusions the brain is bruised due to contact between the brain and the inside of the skull, this may result in a hemorrhage (or bleeding) (Collinson et al., 2009). A cerebral laceration is a tear between the pia mater and the arachnoid mater. The pia mater is the fine vascular innermost membrane enveloping the brain and spinal cord, and is found under the arachnoid mater and dura mater (Granacher, 2007). The arachnoid mater is a delicate fibrous membrane forming the middle of the three coverings of the brain and spinal cord, closely attached to the dura mater,

from which it is separated only by the subdural cleft, but separated from the pia mater by the subarachnoid space (Granacher, 2007). A subdural hemorrhage is damage to the brain resulting from bleeding between the dura mater (the outermost, toughest and most fibrous of the three membranes covering the brain and spinal cord) and the arachnoid mater (Granacher, 2007). Intracerebral hemorrhage is bleeding within the brain tissue and intraventricular hemorrhage is bleeding within the ventricles of the brain (Granacher, 2007).

Diffuse or multifocal CHI affects the cells and tissues throughout the brain and is the result of acceleration and deceleration of the brain tissue. The head does not necessarily strike any object, but the brain tissue is misplaced within the skull forming multiple microscopic assaults to the brain (Granacher, 2007). Diffuse injuries may include diffuse axonal or ischemic brain injuries. A diffuse axonal injury is damage to the white matter of the brain due to acceleration and decelaration motions. An ischemic brain injury is a result of insufficient blood supplied to the brain (Granacher, 2007). Swelling is very common after a CHI and often results in raised intracranial pressure (Granacher, 2007). It is common to find aspects of both focal and diffuse injuries to the brain when a CHI has occurred (Granacher, 2007).

1.2. IMPACT OF SITE OF LESION ON FUNCTIONING

The site of lesion (SOL) is an important variable to establish as it provides information regarding diagnosis, prognosis and aids in rehabilitation and treatment. If one is able to identify the SOL, it provides insight into the functions that are affected and possible treatment measures to undertake (Granacher, 2007). The frontal lobe is situated at the front of the cerebral hemispheres, in front of the parietal lobes and in front and above the temporal lobes.

The frontal lobe is responsible for higher mental functions such as attention, long-term memory, planning, motivation, understanding consequences, understanding acceptable social behaviours and due to the limbic system involvement; the frontal lobe is able to provide memories associated with emotions (Semendeferi, Lu, GoVredi, Schenker, & Damasio, 2002). When the frontal lobe is damaged many difficulties can arise such as loss of smell or taste, easily distracted, creativity and problem solving is diminished or increased, peculiar sexual habits, peculiar social interactions, risk taking and rule-abiding behaviours are affected, individuals may become very impulsive, mental flexibility is impaired and talking may increase or decrease (Semendeferi et. al., 2002).

The parietal lobe is situated above the occipital lobe and behind the frontal lobe and integrates sensory information from different modalities, and parts of the parietal lobe are involved with visuospatial processing. Pathologies in this region result in abnormalities in body image and spatial relations (Blakemore & Firth, 2005). Gerstmann's syndrome can also occur which includes difficulty with writing and difficulty with mathematics, sometimes speech is also affected (Blakemore & Firth, 2005). Self care skills such as washing and dressing are also affected, and difficulty making things and denial of deficits and drawing occurs (Blakemore & Firth, 2005).

The occipital lobe is the smallest lobe and is situated in the rearmost area of the skull; it contains the primary visual cortex, and is the part of the brain where dreams come from (Blakemore & Firth, 2005). Pathology in this area results in loss of vision, visual hallucinations and illusions (Blakemore & Firth, 2005).

The temporal lobe is located beneath the Sylvian fissure on both cerebral hemispheres and is involved in auditory perception and contains the primary auditory cortex, it is also important for processing semantics in both speech and vision, it contains the hippocampus and plays a major role in long term memory (Blakemore & Firth, 2005). Damage to the temporal lobe results in: i) disturbance of auditory sensation and perception; ii) disturbance of selective attention of auditory and visual input; iii) disorders of visual perception; iv) impaired organization and categorization of verbal material; v) disturbance of language comprehension; vi) impaired long-term memory; vii) altered personality and affective behavior; and viii) altered sexual behavior (Blakemore & Firth, 2005) .

It is evident that the type of injury such as a concussion, and the SOL of that injury, for example the temporal lobe, will play a major part in understanding the full extent of the injury, thereby providing information on rehabilitation techniques to administer to each patient with a CHI (Granacher, 2007). All clinical decisions about a patient should be undertaken by a full team of experts including doctors and rehabilitation personnel (Collinson et al., 2009).

CHI often leads to a loss of consciousness (Bergemalm, Hennerdal, Persson, Lyxell, & Borg, 2009; Collinson et al., 2009). This loss of consciousness range in severity, from a mild to severe and is classified according to five different degrees, namely *confusion*, *delirium*, *obtundation*, *stupor*, and *coma* (Bergemalm et al., 2009). In the mildest form, confusion, the individual is able to only carry out simple commands. This often results in apathy, drowsiness and disorientation. When delirium is experienced the individual is reported to be so disorientated and drowsy that they may not remember who they are, and may even experience hallucinations. *Obtundation* is considered a lower level of alertness, as the individual will sleep for long periods

at a time, and when awake remain drowsy and confused. It is during obtundation that the individual may only be kept awake by constant stimulation (Bergemalm et al., 2009). *Stupor* is when the individual has lost consciousness to such a degree that they are only able to regain consciousness by vigorous and repeated stimulation. The final degree of loss of consciousness is *coma* where the individual appears to be asleep but cannot be awakened. Reflexes are generally absent and the individual's respiration rate is slowed (Bergemalm et al., 2009).

1.3 DIAGNOSIS OF A CHI

It is important to accurately diagnose a CHI. There are various subjective and objective diagnostic measures that can be used. The Glasgow Coma Scale (GCS) is one of the subjective measures used to assess the loss of consciousness following CHI. It is used to provide an actual score relating to the loss of consciousness, thus providing information on the severity of the CHI. The GCS is also valuable for improving the clinical decisions regarding management and determining prognosis (Ponsford, Facem, Willmott, Rothwell, Kelly, Nelms, et al., 2004; Perel, Wasserberg, Ramalingam, Shakur, Edwards, & Roberts, 2005; Bergemalm et al., 2009).

The GCS is divided into three sections, namely visual, motor and verbal abilities (See Table 1.1). For each of these areas, patients are given a score indicating their abilities: visual ability is scored out of four; verbal ability out of five, and motor abilities out of six. This gives an indication into the patients' prognosis. The maximum score that can be obtained is 15 with a higher score indicating a better prognosis (Ponsford et al., 2004; Perel et al., 2005). A score of less than or equal to eight is considered severe, nine to 12 is considered moderate and 13-15 is considered mild (Ponsford et al., 2004; Perel et al., 2005).

Table 1.1: Glasgow Coma Scale

	1	2	3	4	5	6
Eyes	Does not open eyes	Opens eyes in response to painful stimuli	Opens eyes in response to voice	Opens eyes spontaneously	N/A	N/A
Verbal	Makes no sounds	Incomprehensible sounds	Utters inappropriate words	Confused, disoriented	Oriented, converses normally	N/A
Motor	Makes no movements	Extension to painful stimuli	Abnormal flexion to painful stimuli	Flexion / Withdrawal to painful stimuli	Localizes painful stimuli	Obeys commands

In a study conducted by Ponsford et. al. (2004), it is reported that 80% of all head injuries are classified as mild with a GCS of 13 - 15. Most of these patients are not admitted to hospital for further examination, and a large number are therefore discharged in a confused state and may suffer repercussions later on. This was confirmed by an international survey conducted by Perel et al. (2005) to determine the value of the GCS, in determining patient prognosis, mortality rates and survival time following a CHI. The results of the survey revealed that only 37% of the participants reported that the GCS was an accurate predictor of the prognosis of these patients. The remaining 63% reported that a more accurate tool of prognostic measurement in conjunction with advanced evaluation was required to provide a more comprehensive picture of the patients' actual disability.

Implementing a more accurate prognostic measure will ensure that clinical decisions such as decompressive craniotomy procedures, intensive care measures and withdrawal of treatment are reliably conducted (Ponsford et al., 2004; Perel et al., 2005).

However, it is postulated that due to many symptoms present in a patient with CHI the GCS alone is not sensitive enough to determine the prognosis (Perel et. al., 2005). The GCS must

therefore not be seen as the only measure to diagnose CHI (Ponsford et. al., 2004). A large selection of clinical measures must be used to determine the person's true state of consciousness and possible outcome (Ponsford et. al 2004).

Measures such as magnetic resonance imaging (MRI) scans, and computerized axial tomography (CAT) scans, should be utilized for diagnosis and decision making (Collinson et. al., 2009). These scans are a necessary source of data as it provides information on type of CHI and SOL.

1.4 COMPLICATIONS FROM A CHI

It is reported that even mild head injuries may cause major neuronal injuries and cerebral dysfunction (Heitger, et al., 2006). CHI can result in many complications such as:

1.4.1 Cognitive deficits including headaches, concentration and memory disturbances, the five different degrees of loss of consciousness, and cognitive deficits resulting from SOL.

Persistence of deficits are reportedly due to many circumstances namely *gender*. In understanding persistence of deficits with regards to gender, Ratcliff, Greenspan, Goldstein, Stringer, Bushnik, Hammond, et al. (2007) performed a study to summate the affiliation between gender differences and cognitive recovery with regards to a CHI. Three hundred and twenty-five patients aged between the ages of 16 - 45 were analyzed in this study; they were admitted to a rehabilitation facility and were receiving rehabilitation within 24 hours post injury. A full neuropsychological follow up was performed one year post injury. Implications for the study revealed that progesterone contains neuroprotective components which is said to protect and/or rebuild the blood brain barrier (Ratcliff et al., 2007). Six neuropsychological tests were

performed on the CHI patients one year after the incident and revealed that females performed better on tasks which required attention and working memory, while males performed better on tasks requiring visual analytic skills (Ratcliff et al., 2007). The study by Ratcliff et al. (2007) used a large sample size and performed many assessment procedures to determine the gender differences. This study is reliable and contains accurate results which indicate that males and females have differing recovery rates, and that recovering abilities is dependent on the hormones and make-up of a male and female patient.

Additional persistence of deficits include a history of head injuries, as the more head injuries one has incurred, the more susceptible the brain is to infections and reduced rate of recovery (Bergemalm, 2003). Furthermore, Bergemalm (2003), reported that most of the cognitive deficits subside after three months post injury, which directly relates to the reports made by Heitger et. al. (2006) who revealed that at 12 months post injury, the head injured participants showed no cognitive deficits. However 15% - 25% of cases have been reported to show deficits in cognitive areas (Bergemalm et. al., 2009).

1.4.2 Neurological deficits such as sensitivity to noise and bright lights, sleep disturbances, visual disturbances and altered reaction times.

1.4.3 Psychological deficits such as, fatigue, irritability, anxiety and depression which tend to put additional strain on the brain's recovery as the brain is bombarded with further difficulties, not only those experienced from the head injury itself (Collinson et. al., 2009). Aspects of psychological dysfunction include post traumatic amnesia, which is a state of confusion and disorientation which occurs immediately after the incident (Ponsford et. al. 2004). There are two types of amnesia being retrograde which is the loss of memory for events that

occurred shortly before the incident and anterograde amnesia which is when the patient has difficulties creating new memories after the incident has occurred. Post traumatic amnesia can last for a few minutes, hours, days, weeks or even months; the duration of the amnesia is a good indicator into the prognosis of the patient (Serious Law, 2010). Post traumatic amnesia is associated with a poorer outcome as stresses in lifestyle do not enable the brain to recuperate on its own, in a relaxed, safe environment (Ponsford et. al. 2004). Stress plays a major role in life in general and may lead to additional injuries and infections. A persistent length of post traumatic amnesia does not allow the brain to recover and decreases the brains plasticity when regenerating abilities and skills (Ponsford, et al. 2004).

1.4.4 Speech and language deficits are well documented as individuals with CHI have difficulty with conversational discourse (Youse & Coelho, 2009). In a study conducted by Youse and Coelho (2009), the social and conversational skills of two CHI participants were analyzed and were then provided with a training and learning skills programme. The participants were unable to develop and manage appropriate content for their conversations, they were unable to perceive the informal needs of the listener, their responses were often inappropriate for the particular conversation; they were unable to maintain the topic and create cohesion during the conversation, and often included irrelevant and tangential information (Youse & Coelho, 2009). The participants present with a lack of social skills due to the CHI (Youse & Coelho, 2009). Furthermore in keeping with speech and language difficulties, Youse and Coelho (2009) reported that decreased attention, memory and executive functioning were the most marked difficulties in the CHI population, therefore resulting in the inability to organize ones thoughts for language expression. Limitations to this study include the fact that there was no information regarding the two CHI participants except for the fact that the one was 16 years post injury and the other was

seven years post injury, and both had received rehabilitation therapy after the incident but were not receiving any therapy at the time of the study. The severity of the injury, the neurological findings and the demographic information was not known.

1.4.5 Ocular and visual deficits were analyzed in a study conducted by Odebode et. al. (2005) to determine whether ocular and visual complications are associated with a head injury. These authors assessed 225 head injured patients in Nigeria, who were diagnosed as having incurred a head injury by the neurological team on the basis of case history, neurological findings and the GCS. These authors reported that 25% of the patients incurred ocular and visual complications. The participant group comprised of 65% males and 35% females, giving an approximate male to female ratio of 2:1. Almost 50% of the ocular and visual injuries occurred in mildly head-injured patients with GCS scores of 13–15 (Odebode et. al., 2005). Severe ocular injury was associated with severe head injury whose GCS was less than or equal to eight on admission. This study made use of a large sample of participants. This reported case history information, GCS scores and neurological data (such as CAT scans) was used in the diagnosis of CHI. A multidisciplinary team was involved giving a more extensive understanding to the difficulties noted and the overall findings and prognosis.

1.4.6 Eye and motor deficits were analyzed in a study conducted by Heitger, et al. (2006) to determine eye damage and persistent motor deficits which occur with mild CHI. Thirty-seven participants were assessed in relation to 37 control participants, and were analyzed at one week, three months and six months post head injury. Residual deficits in eye and arm motor functioning continued. The study found that even in the presence of a mild CHI, eye movements were impaired and motor arm movements were impaired up to one year following

the mild CHI. The study conducted by Heitger et. al. (2006) refers to deficits which persist up to one year post head injury. As abilities reach a plateau following two years after the head injury (Mason, 2004; Ylvisaker & Gioia, 2002), it is important to assess these areas at the two year mark, when abilities are unlikely to change.

1.4.7 Auditory deficits are reported following a CHI, these include hearing impairment, tinnitus, vertigo and dizziness (Ponsford et. al. 2004; Bergemalm et. al., 2009). These deficits can follow immediately after trauma, but can also have a delayed onset and occur even after mild head injury (Bergemalm et. al. 2009). Heitger et. al., (2006) also commented that audition may be impaired due to head injury, even if it is a mild head injury, therefore providing the additional necessity to assess this area of hearing impairment in the CHI population; however this area was not researched in the Heitger et. al. (2006) report, but was mentioned as a probability. Odebode et. al. (2005) also mentioned that in their study there were two cases of auditory nerve involvement. Collinson et. al. (2009) reported that it is common for the patient to suffer a gross impairment of auditory visual learning materials.

1.5 AUDITION IN THE CHI POPULATION

Due to the many complications associated with a CHI, individuals with CHI are exposed to consultations with a range of professionals. These usually include psychiatric, medical, surgical, rehabilitation nursing and neuropsychology consultations. In addition they are often required to attend physical, occupational, and speech and language therapy, and social service consultations (Brown et. al., 2007). There is however limited reports in the literature of audition as an important or relevant area to be assessed post CHI (Brown et. al., 2007). In a study conducted by Brown et. al. (2007) to document the symptoms of head trauma at the time of

incident and one year post recovery, audition was assessed. The scale used to measure audition included whether the patient (i) had normal hearing; (ii) was able to hear conversation at an average level; (iii) had impaired hearing; or (iv) was not testable or hearing status was unknown. It is important to note that no formal hearing tests were conducted in this study and that the auditory component of a CHI was therefore not well documented. The results indicated that impairment in audition was uncommon and if present did not change much one year post CHI.

It is postulated that in most cases hearing impairment in CHI is mainly temporary and tends to dissipate during the post-traumatic period (Bergemalm et. al., 2009). Some patients may however believe that they have some sort of hearing loss especially in more complex situations. This symptomatology is reported to resemble the "King-Kopetsky syndrome, in that patient's present with clinically normal hearing" (Bergemalm et. al., 2009, p.803), yet they struggle when listening to speech in the presence of background noise. For speech perception, especially in difficult hearing conditions such as noisy environments, the individual's cognitive abilities (specifically working memory and phonologic ability) are important. Therefore, the perceived hearing impairment could be a consequence of a cognitive deficits and/or central auditory processing disorder (CAPD). CAPD is described as a disorder, where the brain does not process the sounds that the individual hears even though the individual presents with normal hearing (Mignon, Schminky, Jane & Baran, 2000). It is not uncommon to find CAPD a consequence of a CHI, as auditory brainstem response (ABR) tests often reveals pathology in the early stages of a CHI as well as a possible long term sequalae of a head injury (Bergemalm et. al., 2009). In these instances, patients with normal pure tone audiometry and normal subjective hearing demonstrate deficits when hearing is tested in more complex listening situations (e.g. listening in a noisy environment), determination of direction of a moving sound source and recognition and

identification of specific sounds (Bergemalm et. al., 2009). It is therefore important that individuals with CHI complete a full diagnostic audiological examination as pure tone results alone may not indicate difficulties in hearing (Bergemalm, 2001). Clinical studies have demonstrated that hearing loss is common both in cases of CHI with fracture of the base of the skull (Wennmo & Svensson, 1989) and in cases without fracture (Griffiths, 1979). In transverse fractures of the temporal bone, total and permanent hearing loss on the affected side is often present (Lucertini, Viaggi, Pasquazzi, & Cianfrone, 2001). It was found that with fractures of the temporal bone hearing losses of greater than or equal to 15 dB are reported (Bergemalm, 2003). In both instances, conductive as well as sensorineural hearing losses can be demonstrated.

1.5.1 Conductive hearing loss

A conductive hearing loss refers to "the loss of sound sensitivity produced by abnormalities of the outer ear and/or middle ear" (Martin & Clark, 2006, p. 443). In CHI, peripheral hearing impairment can be as a result of a fracture of the temporal bone, which can be either longitudinal (in 80% of cases) or transverse (in 20% of cases) especially when the otic capsule is involved (Dahiya, Keller, Litofsky, Bankey, Bonassar, & Megerian, 1999). When the middle ear is involved, there can be disruption of the ossicular chain due to fracture or luxation (Bergemalm, 2003). There may also be a conductive component due to bleeding, in which case hearing acuity will return when the accumulated blood is reabsorbed.

1.5.2 Sensory hearing loss

Sensory impairment can be explained as "the loss of hearing sensitivity produced by damage or alteration to the sensory mechanism of the cochlea" (Martin & Clark, 2006, p. 452). In some cases, the stapedial footplate is forced inwards through the oval window. Rupture of the oval window or the round window membrane can cause a perilymphatic leak (Tonkin & Fagan, 1975). This impact causes a pressure wave that can damage the organ of Corti, which is considered the true organ of hearing (Segal, Eviatar, Berenholz, Kessler & Shlamkovitch, 2002). The organ of Corti is known as the body's microphone, consisting of 16 000 to 20 000 hair cells distributed along the basilar membrane. Depending on where the hair cells are situated along the membrane, it determines the pitch and loudness of sound and is also linked to the organ of Corti (Segal et. al., 2002).

1.5.3 Neural hearing loss/Central auditory impairments

Neural hearing loss suggests permanent hearing loss originating from dysfunction of the VIIIth cranial nerve (Debonis & Donahue, 2004), or a central brain dysfunction (Blakemore & Frith, 2005). Central impairments can occur at the level where the hair cells within the cochlea convert the vibrations into nerve impulses that are transmitted by the cochlear portion of the VIIIth cranial nerve to the brain (Zimmerman, Ganzel, Windmill, Nazar, & Phillips, 1993). A corresponding pressure wave can arise through elevated intracranial pressure, which can be transmitted to the inner ear via the internal auditory canal, the cochlear aqueduct and the endolymphatic sac (Fitzgerald, 1996). A pressure wave in the cranial skeleton can also have an impact on the inner ear. The blood supply to the inner ear can be jeopardized, either partly or totally, due to elevated intracranial pressure, or direct injury to blood vessels and thrombosis

(Brownson, Zollinger, Madeira & Fell, 1986). Furthermore, the VIIIth cranial nerve as well as the central auditory pathways can be damaged, and both injuries can contribute to hearing impairment. It is common to find secondary injuries such as diffuse axonal damage and disruption to the central neuronal pathways after CHI (Bergemalm & Borg, 2003). Pathologic ABR results are another common finding in the acute phase of a CHI (Bergemalm, 2001). It is therefore important to use ABR testing as a diagnostic and prognostic tool in the comprehensive audiological test battery.

Griffiths (1979) postulates that the degree of impact will have different effects on hearing loss. The hearing system will be more affected if there is a blow to the head with a hard object as opposed to a soft object, even though both would have had the same power at impact. In sporting activities such as boxing, boxers experience repeated head trauma which causes accumulative damage. The damage however depends on the weight class of the fighters, the number of fights they have participated in, and the number of blows to the head (Lucertini et. al., 2001).

1.6 ONSET AND DEVELOPMENT OF HEARING LOSS FOLLOWING A CHI

There is limited information regarding the recovery of auditory function following CHI. Some studies revealed that an initial hearing loss after a head injury, especially losses in the low and mid frequencies most often diminish or subside during the initial post-traumatic recovery period [time of injury, until the patient has become stable] (Bergemalm, 2003). This period is however variable due to factors such as type and degree of head injury (Bergemalm, 2003). The majority of hearing losses in CHI with and without fracture often subside within the post-traumatic period or within the first six months of recovery (Bergemalm, 2003; Bergemalm & Borg, 2003). Sometimes the hearing impairment will persist, and some may even progress

(Podoshin & Fradis, 1975). Ylvisaker and Gioia (2002) identified that hearing loss reaches a plateau around two years post head injury, which indicates that after the two year mark, there will be little or no progress regarding the affected areas. Most functions would have recovered to the best of their abilities within this period.

1.7 THE ASSESSMENT OF HEARING IMPAIRMENT FOLLOWING A CHI

There is no evidence of a standardized assessment protocol recommended for the evaluation of hearing functioning following a CHI. Some studies revealed that only pure tone audiometry are used to assess hearing following a CHI (Bergemalm & Borg, 2001; Brown et. al. 2007; Sanjay, Naresh & Ashis, 2010). These studies state that a comprehensive evaluation of the auditory system following a CHI should be conducted using both basic and more advanced hearing tests (Brown et. al., 2007; Sanjay et. al. 2010). It is therefore proposed that in order to obtain a comprehensive picture of the integrity of the auditory pathways it is necessary for patients with CHI to undergo an extensive diagnostic audiological assessment that include basic and advanced tests (Sanjay et. al., 2010). The basic test battery should include otoscopic examination, immitance audiometry, pure tone audiometry and speech audiometry. The advanced tests include otoacoustic emission testing (OAEs) and auditory brainstem response testing (ABRs) (Sanjay et. al., 2010).

1.8 RATIONALE

Hearing difficulty is known to be a consequence of head trauma (Mellergard & Mathiesen, 1998). There have however been very few studies in the field of audiology which document the long term hearing impairments following adult CHI (Abd Al-Hady, Shehata, El-Mously & Sallam, 1990; Bergemalm, 2003; Bergemalm & Borg, 2001; Bergemalm & Lyxell

2005; Bergemalm et. al., 2009 and Brown e. al., 2007). Arlinger (2003) reports on the review of negative consequences of undetected hearing loss. The majority of these studies conducted did not incorporate modern audiological technology such as, OAE and ABR testing. Using only basic audiological measurements (e.g. otoscopic, pure tone audiometry and tympanometry) limited information is provided about the entire auditory system. The studies lack description of the SOL and therefore no knowledge is gained regarding impact of SOL on hearing loss. Of the few studies published, none have been documented the presence of hearing loss following CHI in developing countries such as South Africa. The proposed study may provide additional insight into the area of long term hearing impairment as a result of a CHI within developing countries such as South Africa. No evidence has been found that within the South African context, auditory competence is investigated as part of a full diagnostic examination following a CHI. Similarly, developed countries such as Holland, USA and Norway appear to have no documented protocol in place for full audiological test batteries to be performed on CHI patients (Brown et. al., 2007; Bergemalm & Borg, 2001; Naugle, 1990). However the few studies that have reported on the importance of audiological assessment following a CHI have all been conducted in Scotland, Sweden and Holland (Brown et. al., 2007; Bergemalm & Borg, 2001; Naugle, 1990). Although hearing impairments have been documented in a number of studies, the results cannot be generalized to the South African context, as each country presents with its own laws, procedures and healthcare acts. In South African there are no laws or policies that refer to the importance of compulsory audiological assessment post-CHI as the health care acts do not acknowledge hearing loss as a possible deficit following a CHI. In addition, there are discrepancies within the South Africa context in terms of living standards, culture, economic

status and the healthcare facilities at their disposal (Bornman, 2004). It is therefore relevant that this research aims to describe the auditory functioning of adults with CHI in South Africa.

CHAPTER 2: METHODOLOGY

This section will focus on the design of the study in relation to the primary and secondary aims of the study, and will include information such as the participant sampling strategy, participant inclusion criteria, description of the sample, the procedures that were implemented and designed, equipment used for the study and the testing protocols that were performed. This section will also focus on reliability and validity issues, ethical considerations and the analysis of data and statistical procedures used.

2.1 PURPOSE OF THE STUDY

The main aim of this study is to describe auditory functioning within the adult CHI population of South Africa. In order to achieve this, the following sub aims were included:

- To describe the medical history and radiological findings in this cohort.
- To describe the audiological findings.
- To relate the audiological findings with the medical and radiological findings.
- To determine the occurrence of hearing loss within the CHI population in South Africa.

2.2 RESEARCH DESIGN

The current research study made use of a non-experimental, descriptive, cross-sectional design (Pope & Bruce, 2008). This study is a non-experimental study as no variables were manipulated, and the participants were selected using non randomized methods, such as specific

participant selection criteria (Maxwell & Satake, 2006). One of the advantages of a non-experimental research design is that the researcher has a certain amount of control over selecting the participants due to the strict selection criteria. In this way the identified participants resemble, as closely as possible, the population that the researcher analyzed (Trochim, 2006). The researcher assessed adult individuals who had sustained a CHI two to five years prior to the assessment, and analyzed their hearing function, while further looking at how variables such as gender, type of injury and site of lesion affected the integrity of the auditory system. Trochim (2006) also states that non-experimental research designs are very important for educational purposes. A disadvantage of a non-experimental design is that it does not test cause and effect relationships but rather looks at associations of variables, meaning that in the current study only associations could be made between hearing loss and CHI (Trochim, 2006).

The current study employed a descriptive research design which is a scientific method involving observing and describing the behaviour of a subject without influencing it in any way (Maxwell & Satake, 2006). An advantage of a descriptive research design is that a lot of information can be attained through description, and involves gathering data and then organizing the data into tables, graphs, charts to display patterns that emerge during the analysis of the data (Maxwell & Satake, 2006).

In a cross sectional study the data is composed at a single point in time, which allowed the results to relate to the larger population as a whole (Maxwell & Satake, 2006). Advantages of a cross sectional study include the fact that the study is cheaper, and requires no follow-up (Trochim, 2006), and that the researcher can control measurements and maximize completeness of important key data (Trochim, 2006; Pope & Bruce, 2008). Disadvantages of a cross-sectional

design are that it can only report on correlations and not causal relationships. Generalizing the data from the sample tested can be difficult; certain experiments may require very large sample sizes; and researcher selection bias may interfere with the individuals selected for the testing process (Thisted, 2006). Within the current study all efforts were made to minimize the effects of these factors for example a sample of 30 participants were decided upon as large enough sample size to determine closed head injury and associated hearing loss (Thisted, 2006). The participants who agreed to participate in the study were unknown to the researcher thereby reducing the risk for tester bias.

2.3 PARTICIPANTS

2.3.1 Participant sampling strategy

A non-probability sampling strategy, purposive sampling was used to select participants for this study. Pope and Bruce (2008) report on a type of non-random sampling, in which a smaller group of key individuals are targeted to focus on or represent the attitudes, interests or attributes of a larger sample group. The researcher intentionally selected participants who would provide the best information to address the purpose of this research (McMillan & Schumacher, 2001). An advantage of purposive sampling is that the researcher is left with a sample of subjects in which certain characteristics are evident, enabling the sample population to replicate the characteristics that are found in the targeted population (Maxwell & Satake, 2006). “Perfect replication of a population parameter is highly improbable or impossible to achieve” (Maxwell & Satake, 2006, p. 99). Ultimately, the researcher minimized the amount of errors in selecting the participants by adhering to a set of structured, well-defined inclusion and exclusion criteria that

effectively eliminated unwanted characteristics in individuals which could have biased the sample.

2.3.2 Participant selection criteria

A total of 30 participants were included in the current study. Participants were selected according to the following selection criteria:

Table 2.1: Participant selection criteria: Inclusion Criteria

Criterion	Justification	Method
1. Aged between 18 and 65 years.	Participants were considered adults at the age of 18 years, and were able to give their own informed consent (Pope & Bruce, 2008) Due to geriatric hearing loss, participants were required to be younger than 65 years (Granhdhi, Dechert, Malhotra, Aboutano, Wolfe et. al. 2008), to minimize the effects of presbycusis (Pope & Bruce, 2008)	The researcher assessed age with the use of the participant files, date of birth and identity numbers.
2. Diagnosis of a CHI.	According to the aims of the study, a CHI diagnosis was required, so that results related to that specific CHI population.	Patient medical files were examined to ensure a CHI diagnosis.
3. No history of hearing loss prior to the CHI.	An already present hearing loss would be a confounding variable and would influence the results of the study. (Bukard, Don & Eggermont, 2007).	Through the use of patient medical files, as well as case history data.
4. No history of long term noise exposure.	Extreme noise exposure can lead to a loss of hearing sensitivity and may interfere with the reliability of test results (Bukard, et al., 2007).	Through the case history data.
5. CHI acquired two to five years prior to the study, as the study endeavored to look at long term auditory effects, therefore the 2 year period.	Abilities reach a plateau two years post CHI, therefore abilities are unlikely to change after the two year milestone (Bergemalm, 2003). The five year cut off is to ensure that the participants fall with the age criteria of less than 65 years.	The researcher accessed participant files, which presented dated records as well as conversed with relatives and friends to ensure the documents, were dated correctly.
6. Intact cognitive abilities such as attention, reception and processing commands.	Cognitive abilities were required so that the participant was able to complete the full audiological test battery, which included tests where the participant was actively involved (Bukard et. al., 2007).	The researcher telephoned the participant and their family to ensure that the participant was able to perform the examination tasks adequately and effectively.
7. No exposure to any ototoxic medication at the time of the research testing process. As well as no exposure to any ototoxic medications in	Ototoxic medication can have negative consequences for the auditory system as a whole, and may cause hearing loss (McPherson, Li & Shi, 2006).	The researcher informed the participant and their family of this criterion over the phone, to ensure it was adhered to.

previous years.		
8. The participant must have no family history of hearing loss.	Hearing loss can be genetic, therefore if the participant has a family history of hearing loss, then the results from the assessment may reflect a hearing loss due to family history, rather than due to the CHI alone.	The researcher asked about family history of hearing loss over the telephone, in order to be able to include the participant within the study.
9. Live within the Johannesburg area	Due to the fact that the hearing test was conducted at the University of the Witwatersrand Speech and Hearing department in Johannesburg, the participants were required to live in Johannesburg.	The researcher informed the participant about the location of University of the Witwatersrand over the phone, and they either agreed or disagreed to transport themselves to the University grounds for the study.
10. Good understanding of the English Language.	The researcher was first language English speaking, and therefore it was important for the participants to understand English so that any instructions, questions, answers were understood.	The researcher looked at participant records to see what their first language was, as well as conversed with the participant over the phone when the study was discussed with them.

2.3.3 Participant description

Sample size is important as the number of participants used in a sample should be large enough to provide enough information to be able to generalize to the larger investigated population, as well as minimize the influence of abnormal variables (Beauchamp & Childress, 2008). Within the current study, the researcher assessed 30 participants who adhered to the participant inclusion criteria, to represent the audiological attributes of a larger CHI population of South Africa. The total sample of participants was analyzed according to a variety of critical variables which included gender, type of CHI, SOL and ratings on the GCS. Beauchamp and Childress (2008) reported that statistical regularity encourages the random selection of a number of variables based on a larger group of variables in order to represent characteristics of the greater population.

There were a total number of 30 participants who were included in the current study. The mean age of the participants was 31 years (range 18 – 63 years; standard deviation (SD) - 13.4

years). Gender distribution included seven females (23%) and 23 males (77%). These results are displayed in Table 2.2.

Table 2.2: Description of Sample

Participant number	Age	Gender	Ethnicity
1	24	female	white
2	18	male	white
3	19	male	white
4	20	male	white
5	19	male	white
6	18	male	white
7	30	male	white
8	21	male	white
9	35	female	white
10	60	female	white
11	18	female	white
12	21	male	white
13	38	male	African
14	20	male	African
15	29	male	African
16	39	male	African
17	52	male	white
18	30	male	African
19	20	male	white
20	18	male	white
21	29	male	African
22	47	female	white
23	27	female	white
24	56	female	white
25	63	male	white
26	27	male	white
27	28	male	white
28	42	male	white
29	40	male	white
30	23	male	white
SD	13.4		
Range	18 – 63		

It is interesting to note that males made up most of the participants within the current sample, however this finding is in agreement with previous literature which reports that closed head injuries are more likely to occur in males than females (Odebode et. al., 2005). This may be due to the fact that males tend to take more 'risks' (Bergemalm et. al., 2009, p 84), and they are less concerned with consequences but more concerned with ideas such as danger and adrenalin (Bergemalm et. al. 2009). This is confirmed by further research that indicates that males out-number females 2:1 in ratio with regards to closed head injuries, due to their 'no fear attitude towards life' (Odebode et. al., 2005, p. 84). Literature also asserts that young males are the most adventurous and most likely to take risks, as males in their 20's and 30's tend to feel that they are 'invincible' (Bergemalm et. al. 2009); whereas those that have had more life experience appreciate the fact that consequences for 'irrational' actions can be fatal or have negative penalties for the rest of their lives (Heitger et. al., 2006, p.67). Age distribution among the genders within the current study are displayed below in Figure 2.1

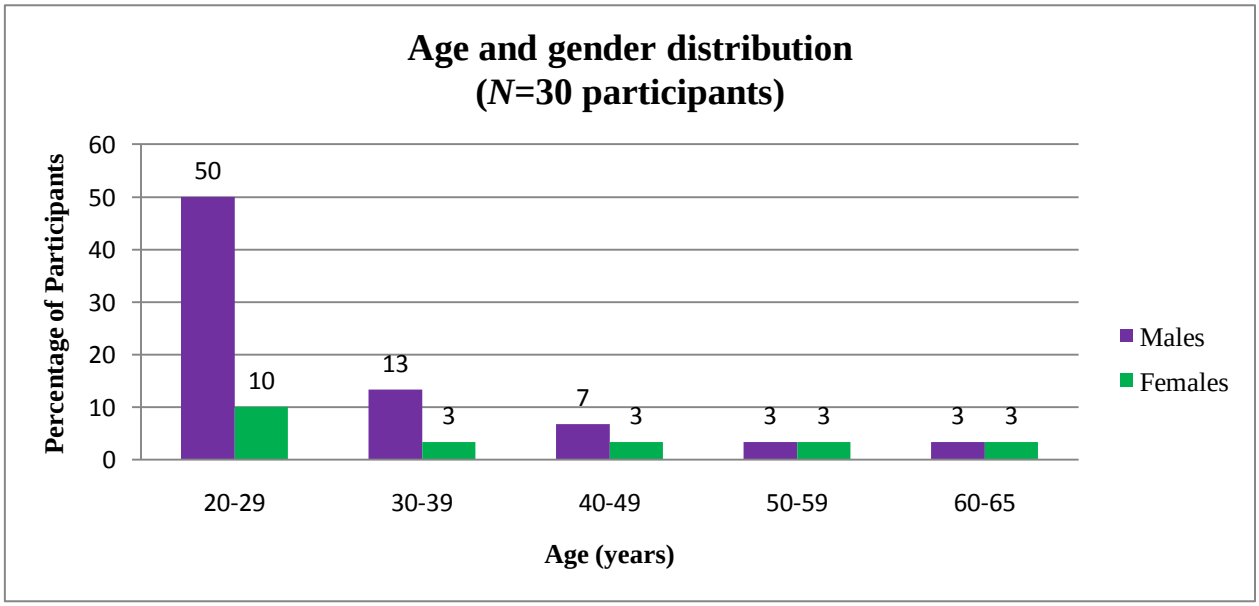

Figure 2.1: Age and gender distribution within the current study (*N* = 30 participants)

It is clear from Figure 2.1, that 15 participants (50 %) within the current study were males between the ages of 20-29 years, four participants (13%) were males between the ages of 30-39 years, two participants (7%) were males aged between 40-49 years and only one participant (3%) was aged between 50-59 years and one participant (3%) was aged between 60-65 years. With regards to the female participants within the study, the majority of the females, 3 participants (10%) were aged between 20-29 years; one participant (3%) was in the 30-39 year range; one participant (3%) was in the 40-49 year range; one participant (3%) was in the 50-59 year range; and one participant (3%) was in the 60-65 year range. These findings directly confirm reports in literature which state that the younger males tend to be more at risk due to their 'irresponsible' behaviour (Bergemalm et. al. 2009), however females in the same age range (although not to such a high degree as males) also tend to be more likely to take risks than their older counterparts (Bergemalm et. al. 2009).

Of the 30 participants, 24 participants (80%) were white and six participants (20%) were African. According to the mid-2010 estimates from Statistics South Africa (SSA), the country's population stands at 49.9-million (SSA, 2010). Africans are in the majority, making up 79.4% of the population (39.7 million people), while the white population constitutes 9.2% (4.6 million people) of the South African population (SSA, 2010). The majority of people living in South Africa are African, therefore the African/white ratio within the current study does not accurately reflect that of the country. Participants were recruited using the records from two private rehabilitation facilities in Gauteng. The majority of records accessed revealed (i) that the majority of CHI patients were not from Gauteng, with many from other African countries, (ii) incomplete records (e.g. no diagnosis; detailed medical and rehabilitation reports); (iii) a large number were not proficient in English, and (iv) the white population in South Africa has more

access to private healthcare than the African population. For these reasons the samples generated from the acceptable records were biased to the white population of South Africa. This is however believed to not have significance on audiological findings of the current study, and is only presented to justify the profile of the participants.

2.4 EQUIPMENT AND MEASURING INSTRUMENTS

2.4.1 Testing facility and equipment

The participants were tested at the University of the Witwatersrand Speech and Hearing Clinic. The hearing assessments took place in a sound proof booth to ensure maximum sound acuity. Following standardized audiological procedures (Smoski, 2008), the researcher worked from the audiometric equipment room, while patients underwent testing in the evaluation room. The audiometric equipment room contained the diagnostic audiometer, including speech audiometry. The equipment used for each hearing test is described in Table 2.3.

All equipment had undergone annual calibration. Biologic calibration was routinely performed prior to every test session.

Table 2.3: Equipment

Test Conducted	Equipment Used
Otoscopic examination	Battery operated Heine Mini 2000 otoscope, with removable and re-usable, speculae.
Immittance audiometry: ✓ Tympanometry ✓ Acoustic Reflexes (AR)	GSI Tympstar, version 1 middle ear analyzer, using a probe tone frequency of 226Hz. Tympanometry nubs of different sizes were utilized; the best fitting nub was used, so as to ensure a good fit.
Pure tone audiometry	The AC40 clinical audiometer was used, which is a 2-channel audiometer, using ISO regulated headphones to conduct the test.

Speech Audiometry: ✓ Speech Reception Testing (SRT) ✓ Most Comfortable Loudness Level (MCL) ✓ Uncomfortable Loudness Level (UCL) ✓ Speech Discrimination Testing (SDT)	The AC40 clinical audiometer was used, which is a 2-channel audiometer, using ISO regulated headphones to conduct the test.
Otoacoustic Emissions	Capella OAE system.
Auditory Brainstem Response	ABR system EP15/EP25 Interacoustic Eclipse was utilized.

Infection control measures were carried out according to the standards of the University of the Witwatersrand's Speech and Hearing Clinic (USHC) which are based on published literature (Pinsker, 1972). All consumables such as ear nubs, speculae and insert earphones were disinfected in Milton®'s solution and left to soak overnight to ensure maximum sterility. Conductive EEG paste, micropore, surgical tape and Nuprep abrasive skin prepping gel was utilized for the ABR recordings. Ultracide, hand sanitizer and alcohol swabs were used for infection control.

Additional consumables included alcohol wipes to disinfect headphones and control panels, and these were thrown away once used. Ear buds were utilized to prepare the skin for ABR electrode placement and these were thrown away once used. NuPrep ® exfoliate gel was used to scrub the skin for ABR impedance measures. Transpore ® tape was utilized to secure the electrodes in place during ABR testing.

2.4.2 Case history questionnaire (see Appendix A)

The case history questionnaire was designed to provide the most accurate and detailed information useful for the study, and the questions were short so that misinterpretations and leading questions were avoided at all costs (Beauchamp & Childress, 2008). The questionnaire

consisted of many open ended questions so that the participant could add any additional information if necessary (Beauchamp & Childress, 2008). The questionnaire was filled out by most of the participants upon arrival at the University of the Witwatersrand Speech and Hearing Clinic. Of the 30 participants, P1 was in a wheel chair, and unable to write, and therefore her mother filled in the questionnaire on her behalf. Four participants (P13, P14, P15 and P16) were living in a residential facility and were also unable to write, and therefore the home caregiver filled out the questionnaires for those participants. A copy of the questionnaire is found in Appendix A.

The questionnaire probed four main areas: demographic information, medical history, communication difficulties in general, and hearing status.

Demographic information included gender, chronological age, home language as well as date of birth as a means of confirming age.

Medical history included information about previous illnesses, because by identifying and acknowledging prior illnesses, the researcher was able to "classify factors that may have led to long term auditory sequalae following the illnesses" (McPherson et. al., 2006, p.43). Information on any drugs that the participant was exposed to, was also important, as any ototoxic medication may have lead to some auditory deficit which would have confounded the results, as would previous head injury, and otological surgery (McPherson et. al., 2006), and therefore questions that probed these variables were included in the case history questionnaire.

The researcher then asked specific questions related to the head injury. Time of onset was determined to provide the researcher with the dates of the incidence, and these dates were cross

checked with the participants' records to ensure reliability of the data obtained. To ensure that the participant had reached the two year plateau of abilities the length of time post injury was also probed (McPherson et. al., 2006). The researcher also asked the participant to describe the cause of the injury as this might have implications for the nature of the injury as well as symptoms (McPherson et. al., 2006). The type of head injury was ascertained and it was cross-checked with participant records to ensure a CHI diagnosis had been made. Loss of consciousness was essential to probe to determine the severity of the head injury and to compare with the Glasgow Coma Scale score in the participants' records as it has been reported that length of unconsciousness will have an effect on the patient's abilities to recover (Bornman, 2004).. The longer a person is in a coma, the more devastating the effects will be on the person's overall functional abilities (Bornman, 2004). This score enabled the researcher to gain insight as to the severity of the participant's injuries, and their recovery as a whole (Bornman, 2004). The case history questionnaire probed questions about effects on speech production, language expression and comprehension, and hearing, to establish that any hearing loss was due to the CHI itself, and not due to any prior illness, surgery or injury. The information on speech and language skills provided information to assist the researcher to provide linguistically appropriate information in all interactions with the participants, including the discussion prior to the testing, instructions during testing, and information regarding the findings (McPherson et. al., 2006). In addition, this information helped to establish that if a hearing loss was found it was attributable to the CHI alone and not due to a prior deficit (McPherson, et al, 2006). Similarly, the case history questionnaire determined if there were known family histories of hearing loss, as well as exposure to noise, so that these variables could be excluded as confounding factors (McPherson et. al., 2006).

To establish a time frame from onset of deficits to plateau of deficits, the researcher asked when the deficits were first noticed, and by whom they were noticed.

A section of the case history questionnaire probed audiological status such as the presence of tinnitus, a sense of "blocked ears", vertigo and dizziness, as well as hearing specific information about the participants hearing in their home and work environments (McPherson et. al., 2006).

The presence of a family history of speech, language, cognitive deficits was probed in the case history questionnaire (McPherson et. al., 2006). Whether or not the deficit interferes with everyday home routines was an additional question to provide the researcher with information about the severity of the deficit (McPherson et. al., 2006). This information was also necessary so that if a hearing loss was found, it may have been attributed to genetics, and not only to the CHI itself (McPherson et. al., 2006).

2.4.3 Audiological Testing

The test battery described in table 2.3 was utilized. All instructions were given in a conventional manner (Bornman, 2004), and all the participants understood the instructions. The testing process took two and a half hours and all participants had been made aware of the time period that the testing would take which was established during the pilot study. All testing was conducted in a sound proof booth.

The researcher began to recruit participants in April 2010, once ethical clearance had been granted from the Human Research Ethics Committee (medical) (see Appendix B). Data collection began in June 2010 and was completed in November 2010.

2.4.3.1 Otoscopic examination

This test is compulsory prior to testing and conducted bilaterally (Clark, Roeser & Mendrygal, 2007). The predominant function of this test is to identify if all outer ear components are intact and functioning adequately; to ensure that the ear canal is free of wax or other obstructions, and to identify any inflammation that may be due to middle ear pathology (Rappaport & Provencal, 2002). Normative data from literature reports a healthy ear to be free from wax obstructions; free from any foreign objects; free from blood and inflammation. The tympanic membrane should be a pearly-grey colour; slightly concave with an evident umbo; cone of light and long handle of malleus; have no perforations, must not present with scarring and no fluid must present behind the tympanic membrane; as well as no evidence of ear canal collapse (Martin & Clark, 2006; Debonis & Donohue, 2004, Clark et. al., 2007). Any abnormalities detected on the otoscopic examination would influence results of forthcoming assessments and may disallow further testing to take place. Therefore all participants were required to present with normal bilateral otoscopic findings, in order for the participants to continue with their participation in the current study.

2.4.3.2 Immittance audiometry

This test includes tympanometry and acoustic reflexes and a recently calibrated tympanometer was used to perform these tests (See calibration certificate in Appendix C). Tympanometry is an objective test used to evaluate the movement of the eardrum and status of the middle ear (Kemp, 2002). Tympanometry measures the ear's ability to transform acoustical energy into mechanical energy, in other words sound waves sent to the tympanic membrane and ossicles are transformed into vibrations, and provide information about ear canal volume, middle

ear compliance and middle ear pressure (Clark et. al., 2007). An appropriate sized ear nub was selected and the pinna was pulled up and backwards so that a good seal was achieved. A normal (Type A) tympanogram is indicated: middle ear pressure is between +50 to -150 daPa (Clark et. al., 2007); Static compliance: 0.27-2.8 cc^3 (Clark et. al., 2007); Ear canal volume: 0.4-1.5cc^3 (Clark et. al., 2007). Martin and Clark (2006) report that if a type A tympanogram with normal compliance is obtained bilaterally, then it is suggestive of normal middle ear functioning.

Acoustic reflexes (AR) measure the stapedius and tensor tympani reflex generated eardrum movement in response to intense sound (Rappaport & Provencal, 2002). They are helpful in detecting particular types of hearing loss in situations where the patient's reliability is questionable (Rappaport & Provencal, 2002). Occassionally, acoustic reflexes point to central nervous system pathology; therefore both ipsilateral and contralateral acoustic reflexes were performed, at 500Hz, 1000Hz, 2000Hz and 4000Hz (Kemp, 2002). Reflexes were set at 70dBHL and were increased by 5dBHL until an accurate reading was determined at each frequency, which is based on the absolute value of the deflection 0.2 – 0.4, as well as downwards deflection morphology (Martin & Clark, 2006). Reflexes are an important tool in a complete hearing test battery as they are used as a cross verification with the type of hearing loss and the site of lesion, and can help identify between a retrocochlear and a cochlear hearing loss (Martin & Clark, 2006). The acoustic reflex should be elicited at 70 to 110 dB SPL, for normal acoustic reflexes, and for contralateral reflexes, at 70 to 95 dB SPL (Rappaport & Provencal, 2002). Reflexes below 60 dB SPL compared to the pure tone threshold are indicative of cochlear pathology (recruitment) (Rappaport & Provencal, 2002). Absent or elevated reflexes are indicative of a severe cochlea hearing loss, conductive pathology as well as a retrocochlear lesion (Martin &

Clark, 2006). Lesions in the auditory cortex indicate normal acoustic reflex thresholds (Martin & Clark, 2006).

2.4.3.3 Pure tone audiometry

Following immittance testing, pure tone audiometry was conducted on a recently calibrated audiometer (See calibration certificate in Appendix D). Pure tone audiometry is the key hearing test used to identify hearing threshold of the participants at frequencies between 250Hz and 8000Hz, enabling determination of the degree, type and configuration of a hearing loss, as well as providing information about laterality and symmetry of the hearing loss (Bess & Humes, 2008). Laterality is described by Bess and Humes (2008), as providing information about whether the hearing loss is unilateral (hearing loss in one ear) or bilateral (hearing loss in both ears). Symmetry of the hearing loss refers to whether the configuration and degree of the hearing loss is the same in both ears (Bess & Humes, 2008). As with most clinical tests, calibration of the test environment, the equipment and the stimuli to ISO standards was needed before testing proceeded (Bess & Humes, 2008).

The degree of hearing loss was determined by using Silman and Silverman's classification of magnitude of hearing impairment, and reports that hearing loss begins at a hearing level of 25dB HL, and is shown in Table 2.4.

Table 2.4: Silman and Silverman's (1991) classification of degree of hearing loss

Degree of Hearing Loss	Description
< 26 dB	**Normal hearing**
26 – 40 dB	**Mild hearing loss**
41 – 55 dB	**Moderate hearing loss**
56 – 70 dB	**Moderately severe hearing loss**
71 – 90dB	**Severe hearing loss**
>91 dB	**Profound hearing loss**

A descending method was used, where the researcher began the test at 40dB and decreased in 10dB steps (Roeser, Valente, & Hosford-Dunn, 2002). Configuration of the hearing loss was determined according to guidelines set by Roeser et. al., (2002) which state that:

- A flat configuration is when there is no or little change in thresholds across all the frequencies.
- A sloping configuration is as the frequencies increase so does the hearing loss.
- A low frequency configuration infers that as the frequencies increase the hearing loss is decreased.
- A ski slope configuration refers to a very sharp increase in hearing loss between octaves.
- A high frequency configuration reveals normal thresholds up to 3KHz, after which thresholds drop in the higher frequencies.
- A notch configuration refers to a notched shape loss between 1-3KHz.

Bone conduction testing was not required for this study as the results revealed normal pure tone air conduction results. Masking was also not required. The audiogram was recorded on a standardized audiogram with the necessary space and information to record the results of the otoscopic examination, pure tone audiometry, immittance audiometry and speech audiometry (see Appendix E).

2.4.3.4 Speech testing

Speech audiometry provides information concerning sensitivity to speech materials and acuity or understanding of speech at supra-threshold levels (Smoski, 2008). Speech audiometry has become a fundamental tool in hearing-loss assessment (Smoski, 2008). It can be used diagnostically to examine speech-processing abilities throughout the auditory system, and it can be used to crosscheck the reliability of pure-tone thresholds (Smoski, 2008). Speech audiometry, in conjunction with pure tone audiometry, can aid in determining the degree and type of hearing loss. Speech audiometry also provided information regarding discomfort or tolerance to speech stimuli and information on speech discrimination abilities (Smoski, 2008).

i. Speech Reception Threshold Testing – SRT: The objective of this measure is to obtain the lowest level at which speech can be identified at least half of the time (Smoski, 2008). A VU-meter was utilised as a measure of reliability and validity of speech results. The VU-meter is necessary in order to display a signal level, which is the signal power, strength and intensity of the stimulus at a specified point, and is measured in dB. Through the use of a VU-meter, the researcher is able to monitor the live voice testing of the spondee words, to ensure reliability and validity of results obtained (Smoski, 2008). Spondee word lists [The Central Institute for The Deaf Auditory word List (CID-W1)],

(See appendix F), were utilized for testing purposes. Spondees were used because they are easily understandable and contain information within each syllable, to allow reasonably accurate guessing (Smoski, 2008). In addition to determining softest levels at which patients can hear and repeat words, the SRT was also used to validate pure-tone thresholds because of a high correlation between the SRT and the average of pure-tone thresholds at 500, 1000, and 2000 Hz (Smoski, 2008). The SRT/pure tone threshold must be no more than 6dB difference in order for it to be reliable (Roeser et. al., 2002). According to Martin and Clark (2006) SRT may also give information about a central nervous system disorder or it may provide information about a sloping hearing loss either in the high or the low frequencies.

ii. Most comfortable loudness level - MCL: This test determines the intensity level of speech that is the most comfortable for the participant to hear sounds (Smoski, 2008). For most patients with normal hearing, speech is most comfortable at 40-50 dB above SRT.

iii. Uncomfortable loudness level – UCL**:** this test determines the upper hearing limit for speech (Smoski, 2008). This level provides the maximum level at which word-recognition tests can be administered. UCL can also indicate maximum tolerable amplification (Roeser et. al., 2002). UCL was used to determine the dynamic speech range, which determines the limits of useful hearing in each ear and is computed by subtracting SRT from UCL. A normal UCL will be computed at 70-100 dB above the SRT level (Smoski, 2008)

2.4.3.5 Otoacoustic Emissions Testing (OAE)

The primary purpose of OAEs is to determine cochlear status, specifically outer hair cell function (Bess & Humes, 2008). This information can be used to screen hearing, partially estimate hearing sensitivity within a limited range, differentiate between the sensory and neural components of sensorineural hearing loss, and test for functional (feigned) hearing loss (Bess & Humes, 2008). The information can be obtained from patients who are sleeping or even comatose because no behavioral response is required (McPherson et. al., 2006; Debonis & Donohue, 2004).

For this test the participants were awake, and repeat recordings were performed to ensure comparison and consistency (Hall, 2007). Distortion product otoacoustic emission (DPOAE's) were tested bilaterally at 2 levels, L1/L2 ratio of 65dB/55dB. Frequencies tested were 500Hz, 750Hz, 1000Hz, 1500Hz, 2000Hz, 3000Hz, 4000Hz, 6000Hz and 8000Hz. These frequencies were chosen as they test low to high frequencies, and research has shown them to be of the most sensitive to cochlear changes (Hall, 2000; Lonsbury-Martin & Martin, 2002). The F1/F2 ratio was set at 1.22 as shown to be optimal (Clark et. al., 2007). Time domain and frequency domain were carried out automatically by the Aurical Capella system. Correlations between tracings should be high at above the 70% limit, to ensure reliability of results (Clark et. al, 2007). Hall (2007) recommends a minimum signal to noise ratio of more than 5dB. This test was used to differentiate between cochlear and retrocochear pathologies (Debonis & Donohue, 2004).

Transient evoked otoacoustic emissions (TEOAE's) were performed at a 70dB level (Clark, et al., 2007), 2080 clicks were accepted, signal to noise ratio (S/N ratio) of =/> 5 was used with an emission strength of between -20 to + 25 signal strength (Hall, 2007). Frequencies tested were

1000Hz, 2000Hz, 3000Hz, 4000Hz and 5000Hz. Martin & Clark (2006) interpret the OAE results as: OAEs with a >/= 5 signal to noise ratio, and falling within the -20 to +25 emission strength value is suggestive of normal ear functioning, and therefore no or little conductive hearing loss (Clark et. al., 2007). When outer hair cell functioning is intact, OAEs will be present in a sensorineural hearing loss, thus indicative of a retrocochlear pathology. Absent OAEs in the presence of a sensorineural hearing loss confirms outer hair cell damage, but does not always mean that a retrocochlear pathology is present (Robinette & Glattke, 2002).

2.4.3.6 Auditory brainstem response audiometry (ABR)

ABR is a neurological test used to measure the electric signals that are induced by the brainstem as it responds to sound, and is considered a successful screening tool in the assessment of suspected retrocochlear pathology (Kehrle, Granjeiro, Sampaio, Bezerra, Almeida, & Oliveira, 2008). The ABR is a tool used to diagnose neurological dysfunction in the VIIIth cranial nerve, and the exact place of lesion along the nerve (Hall, 2007; Hall & Mueller, 1998) The current study made use of click stimuli that generated a response from the basilar region of the cochlear (Hood, 1998). The vertex of the head, ground of the forehead and both earlobes were cleaned with alcohol swabs and were scrubbed with NuPrep ® gel and ear buds/gauze to reduce any resistance to impedance. A small amount of conductive paste was placed on the electrodes; the active electrode was placed on the vertex to record the wave V amplitude (in the hair line). An electrode was placed on each earlobe, left and right, and the reference electrode was placed high on bridge of the nose, in line with the vertex electrode. The electrodes were held in place by transpore ® tape. Insert earphones were then placed in the participants ear canals.

A neurological ABR is utilized to identify any abnormalities along the auditory pathway, and to determine exactly where along the pathway the deficit occurred (Roger & Thornton, 2007). An audiological ABR provides a good estimation of the patient's actual hearing threshold, and is used as a good cross-check method with the pure tone testing (Roger & Thornton, 2007). The current study made use of both a neurological and an audiological ABR. Neurodiagnostic protocol was set at 11.1 clicks per second, duration of the click was 0.1ms and the stimulus rate was set at 1100 sweeps. The test was carried out at 90dBnHL, as latencies are necessary for data analysis, and decreased intensities result in increased latencies (Roger & Thornton, 2007). Therefore a high intensity was utilized to obtain clear and reliable waveforms, with masking noise presented to the non test ear (Hall, 2007). Each ipsilateral recording was conducted twice to ensure repeatability and therefore ensure reliability of test results. The wave V absolute latency response was critical in determining repeatability and reliability (Hall, 2007). The Neurological ABR recording was analyzed in terms of morphology of the ABR waveform, repeatability of the wave V absolute latency recording and the I/V amplitude ratio, absolute wave latencies of waves I,III and V, interwave latencies of wave I-III, III-V and I-V and absolute latency difference of wave V (Hall, 2007).

Waveform morphology: "normal ABR recordings obtained at higher intensities (e.g., 75dB nHL) should contain well-defined peaks, and the presence of at least Waves I, III and V for each ear" (Hood, 1998, p.24).

Amplitude of the ABR waveform: Comparison between amplitudes of wave I and wave V, where wave V should be twice the amplitude of wave I (Hall, 2007).

Repeatability of ABR waveforms: The ipsilateral waveforms that are recorded twice at each intensity level must be repeatable in order for the waveform to be considered a reliable recording (Hall, 2007). Repeatable waveforms must be with 0.2ms of each other (Hall, 2007).

Absolute wave latencies of wave I, III and V: According to Hall (2007) absolute latencies refer to the actual time frame at which the particular wave occurs. For wave I the absolute latency is 1.65 ms with a SD of plus or minus 0.14 ms. Wave III must occur at 3.80 ms with a SD of plus or minus 0.18 ms. Wave V must occur at 5.64 ms with a SD of plus or minus 0.23 ms.

Interwave latencies: Hall (2007) reports that interwave latency between wave I-III must be at 2.15 ms with a SD of plus or minus 0.14. Interwave latency between wave III-V must be at 1.84 ms with a SD of plus or minus 0.14 ms. Interwave latency between wave I-V must be at 3,99 ms with a SD of 0.20 ms (Hall, 2007).

Absolute wave latency difference of wave V: The absolute latency difference of wave V between the left and right ears should be at 0.3/0.4 ms with a SD of plus or minus 0.11 ms (Hall, 2007).

The Audiological ABR recordings began at 40dBnHL if normal hearing was detected, and at 70dBnHL if a hearing loss was detected (Hall, 2007). Ipsilateral recordings were conducted twice at each intensity level. It was important to note the waveform morphology, waveform repeatability, and absolute latency of wave V (Hall, 2007).

Although the ABR provides information regarding auditory function and hearing sensitivity, it is not a substitute for a formal hearing evaluation, and results should be used in conjunction

with behavioral audiometry whenever possible (Kehrle et. al., 2008). Clibration of equipment was from 30/04/2010 until 30/04/2011 (see calibration certificate appendix G)

2.5 PROCEDURES

2.5.1 University ethics committee application for clearance to conduct study

Prior to commencing the study a clearance certificate from the University of the Witwatersrand Human Research Ethics Committee - Medical (HREC) was obtained: protocol number M10362 (Appendix B).

2.5.2 Development of test battery

The researcher compiled a test battery that was able to provide the most relevant information with regard to the research topic. A case history questionnaire was essential for understanding the full extent of the participants' audiologically related difficulties, both prior to and after sustaining the closed head injury. A basic hearing test battery included otoscopic examination, immittance testing, pure tone testing and speech testing (Fischer & Corcoran, 2007). In order to obtain objective, subtle and more neuroaudiological information about the integrity of the hearing system (Fischer & Corcoran, 2007) OAE and ABR testing were included in the test battery as well.

2.5.3 Pilot study: Description of the sampling procedure

The same steps as outlined in the main study were carried out for the pilot study.

2.5.4 Pilot Study

Lancaster, Dodd and Williamson (2004) refer to a pilot study as a small experiment designed to test logistics and gather information prior to a larger study, in order to improve the quality and efficiency of the primary study. The pilot study was used to detect deficiencies in the design of the study and the procedures, so that any issues were addressed before commencement of the main study. Three of the participants that met the inclusion criteria agreed to participate in the pilot study. Table 2.5 provides information on what the pilot study aimed to achieve.

Table 2.5: Objectives, Materials and Equipment, Procedures, Results and Recommendations of the pilot study

Objectives	Materials & Equipment	Procedures	Results	Recommendations
To ensure that both the information sheet and the consent forms were clear and able to gather the relevant information for the current study.	Information sheet (see appendix H) Consent form (see appendix I).	Each participant was given time to read the information sheet and was asked if he/she understood what was written (any ambiguities present). Each participant was then asked to read and sign the consent form to indicate their clear understanding of the study, what it entails and to give their written consent to continue with the study.	No discrepancies were detected, and all the information was clear and accurate.	No changes were made to the information sheet and the consent forms.
To ensure that the case history questionnaire was understandable and probed the relevant questions.	Case history questionnaire (see appendix A).	Each participant was given time to fill out the questionnaire and to ask any questions. The researcher also asked additional questions with regards to the case history questionnaire to ensure that the participant understood everything and answered appropriately	No discrepancies were detected, and all the information was clear, accurate and relevant for the study.	No changes to the case history form were required.
To ensure test equipment and facilities were calibrated and in full working order with no difficulties.	See table 2.3 for the equipment used.	By conducting the full basic and advanced test battery all the equipment was analyzed and any difficulties were noted so that the issues could be addressed prior to commencement of the main study.	All equipment and measures were working effectively and efficiently.	No changes were required.
To determine the	Watch	The researcher took note of	The time to	The participants were

length of time required to complete the data.		the time from case history taking to the final feedback at the end of the process.	complete the data was approximately two and a half hours.	informed that the test would take two and a half hours to complete.
To measure the ease of capturing the data and encoding it.	Conventional test battery forms. Printers for each advanced test so that information can be printed and maintained in participant files.	The researcher wrote down each result on a formal hearing test form (see Appendix E), printouts of advanced hearing tests were made for further analysis. All data were placed in written form so that the researcher was able to encode data into an excel spreadsheet.	Coding and capturing of data was done with ease.	No changes were recommended.

2.5.5 Participant Recruitment

The researcher contacted two main neuro-rehabilitation centers within the Johannesburg area and asked for their participation within the study. Permission was granted by the two Chief Executive Officer's of the rehabilitation centre's, for the researcher to review their client files in order to identify individuals who would fall within the participant inclusion criteria (see appendix J). The researcher was able to identify 60 individuals who were suitable, from which only 33 agreed to participate in the study. Of the 33 participants who agreed to participate in the study, three were used in the pilot study, and the remaining 30 were used in the main study.

The researcher telephoned all the individuals that were identified and informed them about the study. The researcher invited the individuals to participate in the study.

Appointments were made for each participant on a date that suited the participant.

On arrival at the University Speech and Hearing clinic the participant was given a written information sheet. This information sheet detailed all information discussed with the participant over the phone during recruitment. Written information was given as a measure of ensuring

clarity, and to ensure full informed consent (see appendix H). The presence of the researcher at the time that the participant was given the information sheet, allowed the participant to ask questions. The participant then completed a consent form prior to testing (see appendix I).

2.6 RELIABILITY AND VALIDITY

Reliability is the "consistency" or "repeatability" of the measures involved in the research study and ensures that the experimental study is stable (Pope & Bruce, 2008). It is the extent to which a research study will yield the same results on repeated trials (Pope & Bruce, 2008). Without the ability to consistently repeat the study using the same equipment and procedures, researchers will be unable to draw conclusions, formulate theories, or make claims about generalizing the data to the larger population, from which the sample of participants was taken (Pope & Bruce, 2008). Reliability ensures that data is able to be reproduced on the same subjects, under similar test circumstances (Schiavetti & Metz, 2002).

In the current study reliability checking was performed by ensuring that all the equipment was efficiently calibrated, and sound proof booths were utilized for the appropriate test procedures. The full audiological test battery was constantly reviewed during testing to ensure that the results were congruent to each other (Pope & Bruce, 2008). With regards to ABR testing the fact that all recordings were conducted twice, ensured the reliability of the results (Pope & Bruce, 2008).

This study made use of internal consistency reliability. This form of reliability is used to judge the consistency of results across items on the same test (Pope & Bruce, 2008). In this research study, the testing protocols were used to determine auditory functioning along the

auditory pathway; however, many testing procedures were completed so that internal consistency was ensured. For example, comparing the pure tone average at 500Hz, 1000Hz and 2000Hz, to the SRT score, was used to ensure reliability of results. The auditory ABR is used as a crosscheck with the pure tone audiometry, to ensure internal consistency of results, and ensuring that the equipment is calibrated and in good working condition, to supply reliable results.

Validity is the extent to which a test measures what it claims to measure. It is vital for a test to be valid in order for the results to be accurately applied and interpreted (Pope & Bruce, 2008). It is important to note both *external* and *internal* validity. External validity was ensured by use of the participant inclusion criteria, and the inclusion of 60 ears to determine the possible results. A threat to external validity would relate to the appropriateness of the sample of participants in relation to the CHI population as a whole (Maxwell & Satake, 2006).

Internal validity relates to the specific design of the study, the measurements used, and the decisions regarding which measures are important to include in the study (Maxwell & Satake, 2006).

This study made use of construct validity which refers to the degree to which the measure reflects some theoretical construct or explanation of the behaviour/characteristic being measured (Schiavetti & Metz, 2002).

Each individual participant underwent the same variety of audiological tests thus ensuring reliability and validity, by correlating the audiological findings. By consistently

comparing the measures of otoscopy, tympanometry, pure tone measures, speech testing, OAE and ABR measures, reliability and validity were ensured (Meline 2006).

External validity refers to the extent to which the results of a study are generalizable or transferable. Generalizability refers to the extent to which research findings and conclusions from a study conducted on a sample population can be applied to the larger population and transferability is the ability to apply the results of the research in one context to another similar context (Pope & Bruce, 2008). In the current study a threat to external validity was population validity, as the population selected was only adults and can therefore not be related to the paediatric population. In addition the population consisted of mainly white male participants, which in turn serves as a threat to external validity as the results may not be able to be generalized to the additional racial groups in South Africa which include the African, Indian, Coloured and Asian population. Meline (2006) also suggests that the researcher's behaviour, appearance and bias in terms of observations have a negative effect on the validity of the results. However through the use of a variety of testing procedures both subjective and objective, as well as through the analysis of recorded data through descriptive and inferential statistics, researcher effects on population validity was limited.

2.7 ETHICAL CONSIDERATIONS

Participants were asked to volunteer for this study; the researcher described the testing process in detail over the phone, and made it clear that it was completely voluntary to participate. Once the participants arrived at the Hearing Clinic, the researcher described the testing process once again, once oral consent was given, a written consent form was then handed to the participant to sign (see appendix I). It was made very clear that the participant was able to

withdraw from the study at any time with no consequence to them. Written consent was signed with the participants' knowledge that all information obtained would remain confidential.

All participants signed an Informed Consent (see appendix I) which had evidence of:

(A) *Disclosure* - the participant was fully informed as to the nature and purpose of the research, the procedures to be used and the expected benefits to the participant and/or society.

(B) *Understanding* - The participant understood what was explained and was given the opportunity to ask questions and have them answered by the researcher.

(C) *Voluntary* - The participant's consent to participate in the research was completely voluntary, and free of any intimidation.

(D) *Competence* – The participants all presented with in-tact cognitive functioning to provide consent to participate in the study. If the participant was not physically competent, a designated surrogate provided consent. As stated above participants P1, P13, P14, P15 and P16 were unable to provide written consent and therefore their caregivers provided the written consent on their behalf.

(E) *Consent* - The participant authorized his/her participation in the research study, in writing (Fischer & Corcoran, 2007). Participants were allowed to withdraw from the study at any time, without penalty, and had the right to obtain the results of the study (Moss, 2006).

The researcher ensured that the principles of ethics were maintained throughout the study as reported by Robertson, Ryan and Walter (2007).

- Confidentiality: All the participants were made aware that the information received would remain confidential as no names or personal details would be published in the study.
- Autonomy: The participants were respected at all times and always had freedom of choice whether or not to participate in the study.
- Beneficence and non-maleficence refers to the act of doing 'good' for others (Beauchamp & Childress, 2008), and ensuring that no harm will come to the participants (Beauchamp & Childress, 2008). This was adhered to by the use of strict participant inclusion and exclusion criteria, as well as ensuring that the participants were aware of the benefits and risks at all times. In the current study the major benefit to the participants was that they received a comprehensive, free audiological hearing test, which could provide additional information about CHI. No physical risks were noted, however the fact that the test took a long time (two and a half hours) as well as discomfort due to the insertion of nubs/insert earphones was made clear to all participants prior to consent to participate in the study. If abnormalities were detected, the correct referrals were made to the appropriate professionals such as Ear, Nose and Throat specialists, referrals for additional hearing testing/hearing aid evaluations, or the awareness of the importance of annual hearing monitoring. Therefore it was ensured that the participants received direct benefits from participation in the study.
- Justice: Justice refers to protecting vulnerable populations. Even though the closed head injury population can be seen as a vulnerable population, the researchers use of

inclusion and exclusion criteria as well as the fact that participation was completely voluntary, contributed to attributing 'justice' to the study.

2.8 ANALYSIS OF DATA AND STATISTICAL PROCEDURES

Both descriptive and inferential statistics was utilized to analyze the data.

Descriptive statistics measures specific features within a set of data and therefore allows the researcher to summarize that particular data set (Meline, 2006). Descriptive statistics simply describes what the data indicates through the use of graphs, charts and through the calculation of means - to identify extreme scores or oddly shaped distribution of scores (Meline, 2006). All the tests that took place were analyzed using descriptive statistics. Additionally, descriptive statistics were used to analyze ABR recordings in terms of the wave morphology, repeatability and wave amplitudes.

Inferential statistics is used to infer that the data recorded from the target population, was generalized to the larger population, therefore the researcher was justified in her conclusions based on the data that was collected. In other words, the measurements collected for the 30 participants, was contingent with the larger CHI population as a whole (Meline, 2006). The results of the statistical analyses were carried out using the Statistical Package for Social Sciences (SPSS) version 13(Durrheim, 2006). Inferential statistics in the form of the Wilcoxon Matched Pairs Signed Rank Test and the Kruskal Wallis test were utilized to analyze the data. The Wilcoxon Matched Pairs Signed Rank Test is a non-parametric test used when comparing two related samples or repeated measurements on a single sample to assess whether their population means differ (Meline, 2006). In the current study the Wilcoxon Signed Rank tests was

used to compare the related samples between ABR recording 1 and recording 2 which included, absolute wave latencies of waves I,III and V, interwave latencies of wave I-III, III-V and I-V and absolute latency difference of wave V (Hall, 2007). The Kruskal–Wallis test is most commonly used when there is one nominal variable and one measurement variable, and the measurement variable does not meet the normality assumption of an ANOVA (Meline, 2006). The Kruskal–Wallis test does not make assumptions about normality (Meline, 2006). Like most non-parametric tests, it is performed on ranked data, so the measurement observations are converted to their ranks in the overall data set (Meline, 2006). In the current study the Kruskal-Wallis ANOVA test was used to determine any associations between type of head injury and the ABR recordings of absolute wave latencies of waves I,III and V, interwave latencies of wave I-III, III-V and I-V and absolute latency difference of wave V (Hall, 2007). The Kruskal-Wallis ANOVA test was also used to determine associations between GCS scores and the neurological ABR recordings of absolute wave latencies of waves I,III and V, interwave latencies of wave I-III, III-V and I-V and absolute latency difference of wave V (Hall, 2007). SOL and its association with neurological ABR recordings of absolute wave latencies of waves I,III and V, interwave latencies of wave I-III, III-V and I-V and absolute latency difference of wave V (Hall, 2007) was also analyzed using the Kruskal-Wallis ANOVA test. Significance levels were recorded when the p-value was < 0.05.

CHAPTER 3: RESULTS AND DISCUSSION

The aim of this chapter is to present the results and discussion of the current study, in accordance with the aims of the study. The results of each aim will be described descriptively followed by inferential statistical analysis, with the discussion of the findings presented simultaneously.

3.1 DESCRIBING THE MEDICAL HISTORY AND RADIOLOGICAL FINDINGS IN THIS COHORT

The first sub-aim of the current study was to describe the medical and radiological findings. Table 3.1 displays the type of CHI, SOL and GCS scores for the participant sample.

Table 3.1: Type of CHI, SOL and GCS scores (*N*=30)

Participant number	Type of CHI	SOL	GCS
1	intracranial hematoma	occipital and temporal lobes	3
2	concussion	frontal and parietal lobes	14
3	concussion	temporal lobe	12
4	concussion	frontal and parietal lobes	12
5	concussion	frontal and parietal lobe	13
6	concussion	right temporal lobe	11
7	concussion	frontal lobe	13
8	concussion	frontal lobe	13
9	diffuse axonal injury	frontal and temporal lobes	7
10	intracranial hematoma	temporal and parietal lobes	9
11	concussion	parietal and occipital lobes	13
12	concussion	temporal lobe	13
13	intracranial hematoma	frontal and temporal lobes	4
14	intracranial hematoma	temporal lobe	3
15	diffuse axonal injury	frontal lobe	4
16	brain contusion	occipital and temporal lobes	4
17	brain contusion	frontal and temporal lobes	7
18	concussion	frontal lobe	13
19	concussion	frontal and temporal lobes	13

20	concussion	temporal lobe	14
21	intracranial hematoma	parietal and occipital lobes	4
22	concussion	right parietal lobe	4
23	concussion	frontal and temporal lobes	13
24	concussion	frontal and parietal lobe	13
25	concussion	frontal and temporal lobes	11
26	concussion	frontal and parietal lobes	12
27	concussion	left parietal and temporal lobes	13
28	concussion	temporal lobe	14
29	concussion	temporal and parietal lobes	14
30	concussion	temporal and parietal lobes	14

Types of CHI in the current sample:

Of the 30 participants, 21 participants (70%) sustained a concussion; five participants (17%) sustained an intracranial hematoma; two participants (7%) sustained a brain contusion; and two participants (7%) sustained a diffuse axonal injury. These variables were included so as to establish if any relationships exist between severity of CHI and audiological deficits. As can be seen from Table 3.1, the participant group presented with a wide range of SOL. This information was obtained from the participant medical files which gave descriptions of MRI and CAT scans, as well as descriptions of SOL from doctor's notes. GCS scores are used to judge severity of a head injury (Collinson et. al, 2009), and as can be seen, there was a wide variety in the severity ratings, ranging from mild to severe (refer to Introduction section 1.3 for details on GCS ratings).

Each of the 30 participants suffered one of the documented four types of closed head injuries (as detailed in the introduction section 1.1.1). The distribution of these four types of closed head injuries in the current sample is displayed in Figure 3.1.

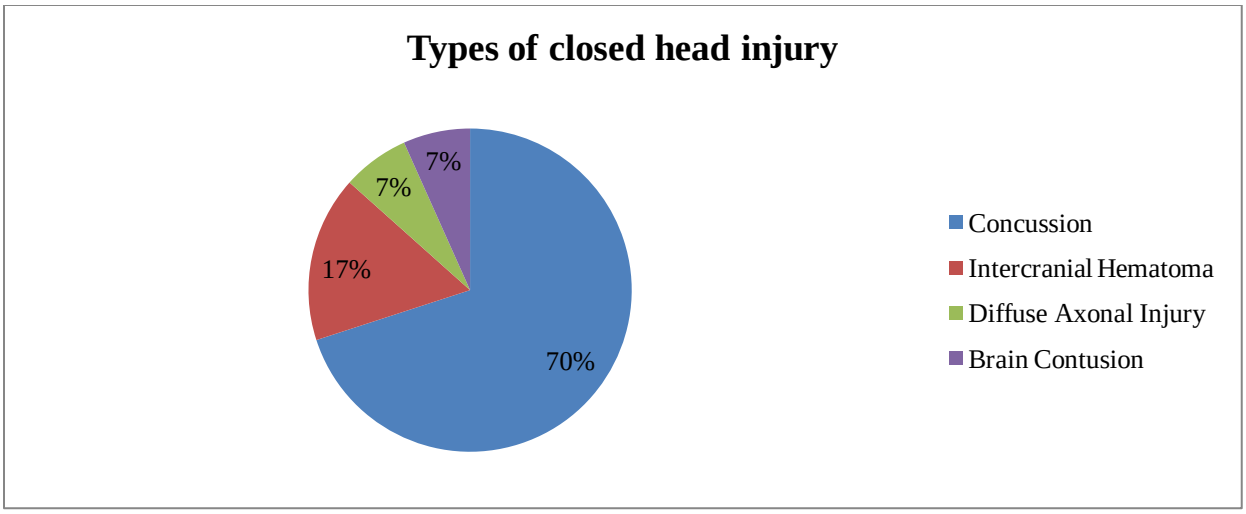

Figure 3.1: Types of CHI (*N* = 30)

A concussion is considered a mild closed head injury as it is temporary and loss of consciousness is not always apparent, however it can still cause deficits such as dizziness, headaches, visual deficits, slurred speech, nausea and vomiting (Collinson et. al., 2009). Many of the closed head injured participants within the current study were concussed during a sporting event such as playing rugby, soccer, polo etc. The remaining types of head injuries are more severe and can result in major loss of functioning due to hemorrhage, neurological deficits, weakness, lack of co-ordination, loss of consciousness, memory and cognitive deficits and can also result in a vegetative state of being (Collinson et. al., 2009).

SOL found in the current sample:

SOL is an important variable to assess as the different lobes are responsible for different functions, and if that particular lobe is damaged , it is likely that the functions for which that lobe is responsible will also be affected (Granacher, 2007).

As depicted in Figure 3.2, there were ten different SOL found in the current study. The majority of participants (30%) sustained a CHI affecting the frontal and parietal lobes whilst five participants (17%) sustained damage to the temporal lobes. Four participants (13%) damaged

their frontal lobes and another four participants (13%) sustained damage to their temporal and parietal lobes. Two participants (7%) damaged their occipital and temporal lobes and two participants (7%) damaged their parietal and occipital lobes. The remaining injuries occurred in one participant (3%) in the right temporal lobe; one participant (3%) damaged the right parietal lobe; one participant (3%) harmed the frontal and temporal lobe and one (3%) participant sustained injuries to the left parietal and temporal lobe.

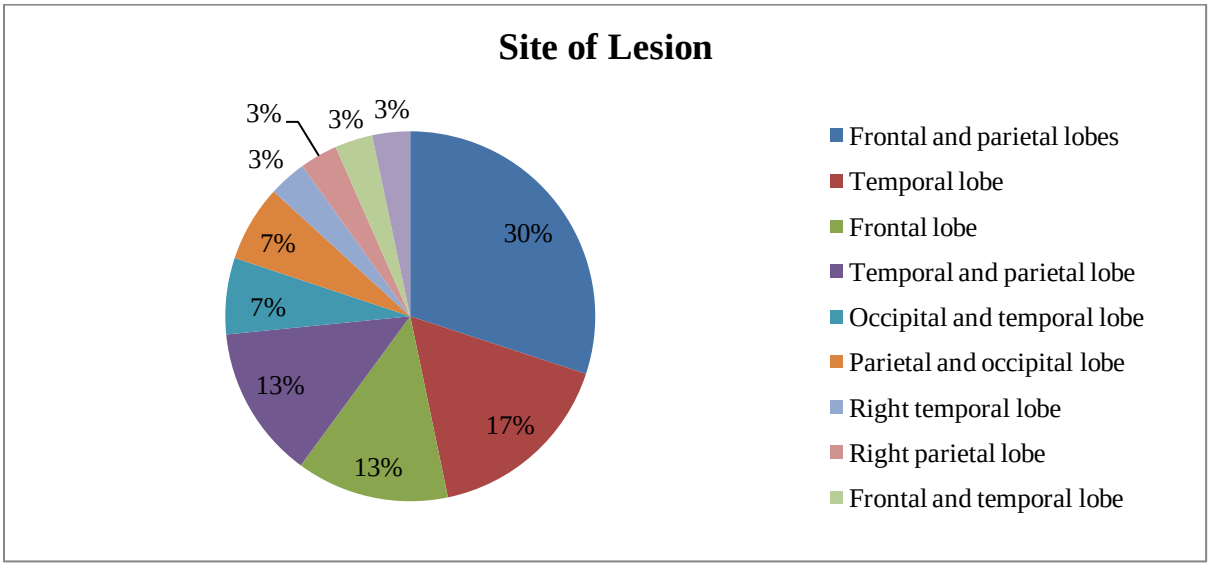

Figure 3.2: SOL within the current study (*N* = 30)

The function of hearing is situated in the temporal lobe (Granacher, 2007), and within the current study 13 participants (43%) acquired CHI which affected the temporal lobe and included other varied SOL.

GCS findings in the current study:

The GCS scores in the current sample revealed a mean of 10.23 (range 3-14; SD = 4.07). Five participants (17%) acquired a score of 14; ten participants (33%) acquired a score of 13; five participants (17%) had a score of four; and three participants (10%) had a score of 12. Two

participants (7%) had a score of 11 with an additional two participants (7%) scoring a total of 7; one participant (3%) had a score of nine; and two participants (7%) had a score of three. Figure 3.3 displays the GCS recordings for each participant within the study.

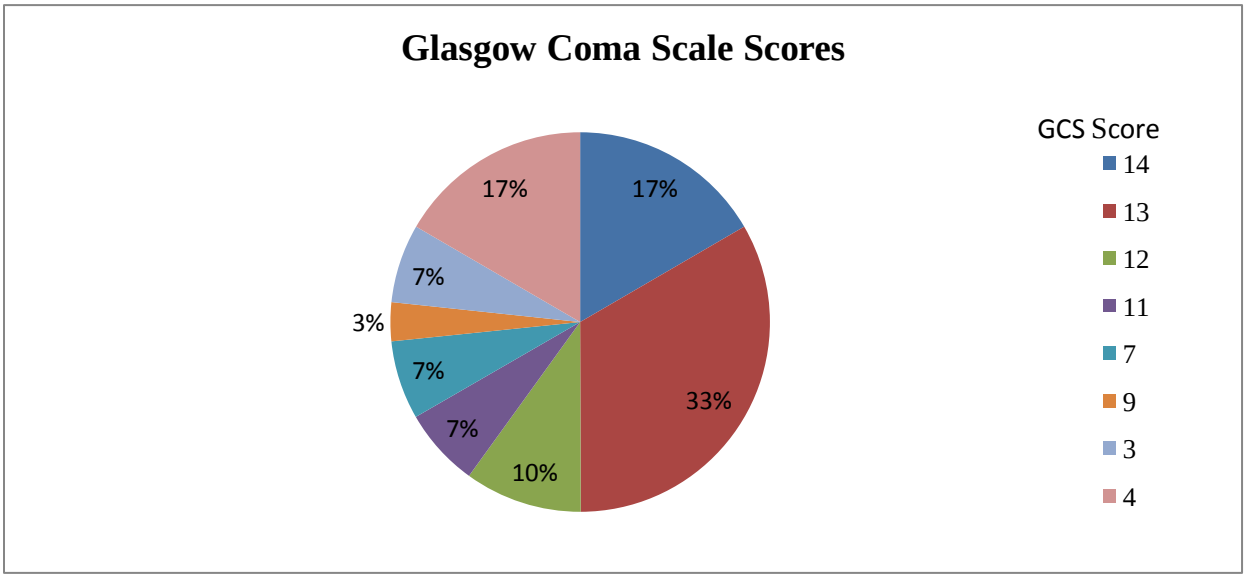

Figure 3.3: GCS scores (*N* = 30)

The GCS scores varied among the 30 participant sample, and the results of GCS and their association with hearing loss was similar to that of SOL and type of hearing loss. GCS has been examined with regards to CHI but was only assessed in relation to patient prognosis (Bergemalm & Borg, 2003), and not in relation to possible hearing loss. The current study revealed no relationship between poor GCS scores and hearing loss. For example participant one who was involved in a near fatal car accident, who received a GCS of 3, did not present with any hearing deficits. Basic hearing tests and advanced hearing tests revealed no deficits. This particular participant lost consciousness, she is currently in a wheelchair, she is unable to talk yet her hearing remained intact. Her hearing results were similar to those participants who received a 'knock on the head' from a poor rugby tackle. The current study revealed that regardless of what

the GCS is, hearing appears to remain relatively intact when GCS is associated with a CHI. Again sample size and distribution calls for caution when interpreting this finding for the current study.

3.2 DESCRIBING THE AUDIOLOGICAL FINDINGS IN THE CURRENT STUDY

The second sub-aim of the current study was to describe the audiological findings of adults with closed head injuries.

The full audiological examination results will be divided into two sections: Section A will describe and discuss the results of the basic audiological tests, and section B will describe and discuss the findings of the more advanced audiological tests.

3.2.1 Section A: Results of the basic audiological tests

The basic audiological test battery included the otoscopic examination, immittance testing, pure tone testing and speech testing. Normal results on basic testing procedures according to normative data include an otoscopic examination that is clear with no abnormalities detected (NAD), type A tympanograms bilaterally, pure tone thresholds within normal limits across all frequencies, speech reception threshold (SRT) correlating to the PTA within 6dB (Silman & Silverman, 1991; Roeser et. al., 2002; Kemp, 2002; Martin & Clark, 2006) and normal speech discrimination abilities which includes the most comfortable loudness level (MCL) which should be 40-50dB above the SRT (Roeser et. al., 2002; Kemp, 2002; Martin & Clark, 2006).The threshold of discomfort (TD) which is the loudest sound the participant can listen to, is used to calculate a dynamic range score by subtracting the SRT from the TD (Roeser

et. al., 2002; Kemp, 2002; Martin & Clark, 2006). The dynamic range (DR) should not be less than 60dB (Roeser et. al., 2002; Kemp, 2002; Martin & Clark, 2006).

The basic hearing test results including otoscopic examination, immittance testing, pure tone testing and speech testing findings are all depicted in Table 3.2.

Table 3.2: Basic hearing test results including otoscopic examination, immittance testing, pure tone testing and speech testing (*N*=30)

Part. Number	Age	Gender	Otoscopy		Tympanometry		PTA dB		SRT dB		MCL dB		TD dB	
			R	L	R	L	R	L	R	L	R	L	R	L
1	24	F	NAD	NAD	A	A	15	11.6	10	10	60	50	95	95
2	18	M	NAD	NAD	A	A	-3.3	0	0	5	50	45	100	100
3	19	M	NAD	NAD	A	A	0	3.3	5	5	45	45	100	100
4	20	M	NAD	NAD	A	A	5	5	10	10	50	60	100	100
5	19	M	NAD	NAD	A	A	10	8.3	15	10	35	40	100	100
6	18	M	NAD	NAD	A	A	5	8.3	10	10	50	50	100	100
7	30	M	NAD	NAD	A	A	1.6	1.6	5	5	45	55	90	100
8	21	M	NAD	NAD	A	A	5	1.6	5	5	45	55	95	100
9	35	F	NAD	NAD	A	A	5	3.3	10	5	60	55	100	100
10	60	F	NAD	NAD	A	A	11.6	8.3	15	15	55	55	95	95
11	18	F	NAD	NAD	A	A	3.3	6.6	10	10	50	50	100	90
12	21	M	NAD	NAD	A	A	11.6	10	15	15	55	55	100	95
13	38	M	NAD	NAD	A	A	15	10	15	15	65	65	100	100
14	20	M	NAD	NAD	A	A	8.3	3.3	5	10	55	50	100	100
15	29	M	NAD	NAD	A	A	8.3	6.6	15	10	55	50	100	100
16	39	M	NAD	NAD	A	A	5	11.6	6.6	15	10	65	90	100
17	52	M	NAD	NAD	A	A	11.6	13.3	15	15	50	50	100	100
18	30	M	NAD	NAD	A	A	1.6	1.6	10	10	60	60	100	100
19	20	M	NAD	NAD	A	A	1.6	0	5	5	45	55	100	100
20	18	M	NAD	NAD	A	A	8.3	5	5	5	45	55	100	100
21	29	M	NAD	NAD	A	A	18.3	13.3	30	15	80	65	100+	100
22	47	F	NAD	NAD	A	A	3.3	3.3	10	5	50	45	100	100
23	27	F	NAD	NAD	A	A	0	0	0	5	50	55	100	100
24	56	F	NAD	NAD	A	A	0	8.3	5	10	45	60	100	100+
25	63	M	NAD	NAD	A	A	11.6	10	15	15	55	45	100	100
26	27	M	NAD	NAD	A	A	3.6	0	0	0	40	50	100	100

Table 3.2: Basic hearing test results including otoscopic examination, immittance testing, pure tone testing and speech testing (*N*=30)

Part. Number	Age	Gender	Otoscopy		Tympanometry		PTA dB		SRTdB		MCL dB		TD dB	
			R	L	R	L	R	L	R	L	R	L	R	L
27	28	M	NAD	NAD	A	A	8.3	0	10	5	40	55	95	100
28	42	M	NAD	NAD	A	A	0	0	5	5	45	55	90	100
29	40	M	NAD	NAD	A	A	5	3.3	10	10	50	60	95	100
30	23	M	NAD	NAD	A	A	0	0	5	5	45	45	100	100

The results of the current study revealed that the audiological performance of all 30 participants on the basic standardized test battery assessment (including otoscopic, immittance testing pure tone testing and speech testing) was within normal limits, according to published normative data (Silman and Silverman, 1991; Roeser et. al., 2002; Kemp, 2002; Martin & Clark, 2006).

As displayed in Table 3.2 none of the participants revealed any abnormalities on the otoscopic examination.

The recorded tympanograms for all participants were classified as type A bilaterally. All acoustic reflexes were found to be within normal limits as the ipsilateral reflexes elicited were all between 70 and 110 dB SPL, for the contralateral reflexes between 70 and 95 dB SPL (Rappaport & Provencal, 2002). The pure tone averages (PTA) were all <26dB, with all pure tone frequencies falling within the normal limits. In the right ear the mean was 5.6dB (range -3.3 to 18.3; SD = 5.7dB) and in the left ear the mean was 5dB (range 0 to 13.3; SD = 5.1 dB). The speech reception thresholds (SRT) correlated with the PTA within 6dB with a mean score of 9.4dB in the right ear (range 0 to 30; SD = 6.1 dB) and 9dB in the left ear (range 0 to 15; SD = 4.2dB). The good correlation confirms the reliability of findings from the current study (Roeser et. al., 2002). The Most comfortable loudness level (MCL) and threshold of discomfort (TD) were also normal, further indicating normal hearing in the current sample. The most comfortable loudness level (MCL) should be 40-50dB above the SRT and this was the case in the current study (Roeser et. al., 2002; Kemp, 2002; Martin & Clark, 2006). In the right ear the mean MCL was 49.5dB (range 10 to 80; SD =11.4 dB) and 53dB in the left ear (range 45 to 60; SD = 6.5dB) (Roeser et. al., 2002; Kemp, 2002; Martin & Clark, 2006).The threshold of discomfort

(TD) is the loudest sound the participant can listen to, just before it becomes very uncomfortable, and when subtracting the SRT from the TD a dynamic range (DR) is computed and should not be less than 60dB (Roeser et. al., 2002; Kemp, 2002; Martin & Clark, 2006). A TD mean of 98dB in the right ear was recorded (range 90 to 110; SD = 3.4dB), and a TD of 99dB in the left ear was recorded (range 95 to 110; SD = 2.3dB), giving a mean DR of 88.6dB in the right ear, and 90dB in the left ear. Hence, all afore described basic audiological findings illustrate no signs of hearing dysfunction when basic hearing tests were used alone.

Basic hearing tests revealed no hearing deficits after the two year plateau mark, which is consistent with findings in many studies such as those conducted by Bergemalm (2003), Bergemalm and Borg (2009), Bergemalm et. al (2009) and Brown et. al.(2007). These studies identified hearing as a possible deficit of a CHI, but nevertheless reported that due to the results of their tests, of which only basic hearing tests were included, hearing loss was found to be evident for only a short period of time, and would generally dissipate one to two years after the closed head injury occurred. Due to the fact that the current study included participants two years post CHI, this may be the influencing factor on these basic hearing test findings. When relating the basic hearing tests of the current study with those achieved by the above mentioned studies, it is evident that the current results are no different from existing evidence of hearing function in the CHI population. In the current study, if a hearing loss was evident prior to the two year plateau mark; it would have resolved by the time of data collection, hence no measurable hearing deficit was evident as indicated by the basic hearing test results of the 30 participants within the current study.

3.2.2 Section B -Results of advanced audiological tests

Advanced audiological tests comprise of OAEs and ABRs.

For interpretation of OAEs in the current study, distortion product otoacoustic emissions (DPOAEs) were regarded to be unacceptable when the signal to noise level was </= 5dB (Hall, 2007), and failed if two or more frequencies failed the test parameters; and transient evoked otoacoustic emissions (TEOAE's) were said to have failed if they were absent at two or more of recordings, and were unacceptable if they were </=5dB (Hall, 2007). Repeatability of the recordings was also regarded as a crucial reliability measure for OAEs in the current study.

3.2.2.1 *Otoacoustic emissions*

Results of the current study indicate that OAEs were normal in 25 participants (83%). Such findings reflect intact cochlea outer hair cell functioning (Debonis & Donohue, 2004); and are consistent with pure tone audiometry findings. These findings were also repeatable for all participants.

Figure 3.4 and Figure 3.5 display the average OAE recordings for both DPOAEs and TEOAEs .

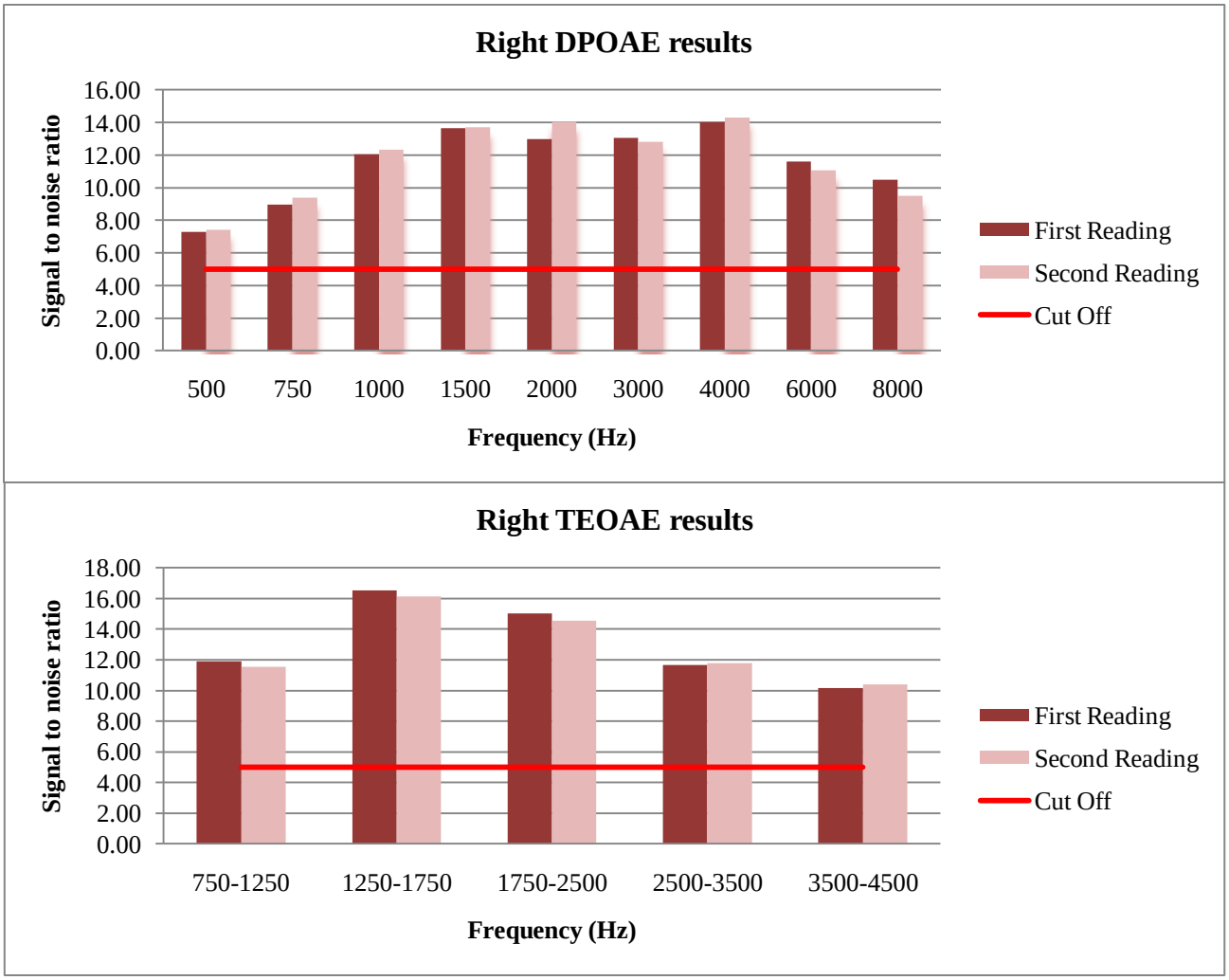

Figure 3.4: Average DPOAE and TEOAE results for the right ear (*N* = 30)

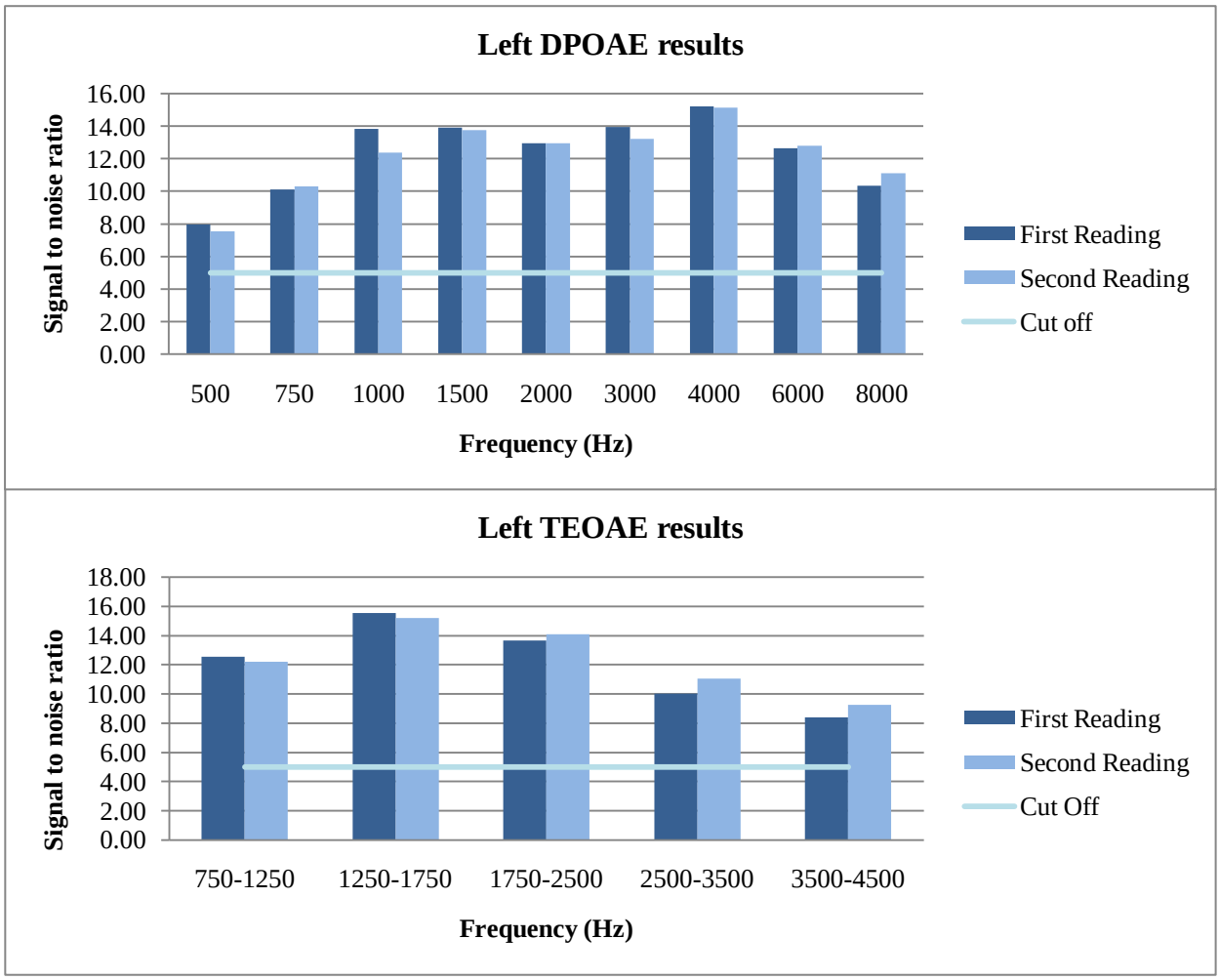

Figure 3.5: Average DPOAE and TEOAE results for the left ear (*N* = 30 participants)

From the figures above it is apparent that the mean scores recorded from all 30 participants revealed good emission strength at all frequencies at all times. However when each OAE recording was analyzed individually for individual participants, abnormal OAEs were obtained in 17% of the sample (5 participants). The results of these participants (6, 13, 21, 26 and 27) will be presented next.

Participant 6:

Participant 6 is an 18 year old white male who sustained a concussion of the right temporal lobe, and had a GCS of 11. His basic audiological test results were all within normal

limits. He was knocked from a boat into the water, when his father attempted to start the engine of the boat. He reported loss of consciousness for a few minutes, and his speech was slurred for five days after the incident. He also revealed some visual difficulties which resolved soon after the incident. He still does not completely remember the incident; therefore he had suffered some form of post traumatic amnesia (Ponsford et. al., 2004). No tinnitus or vertigo was mentioned as a residual deficit from the CHI.

He failed the right DPOAE at 1500Hz, and the right TEOAE at 3500Hz-4500Hz. The 'cut-off' line was assigned by Hall (2007), who reported on normal and failed OAE results, and suggested that in order to pass an OAE recording, the signal to noise ratio must be >/=5 dB. The results are displayed in Figure 3.6.

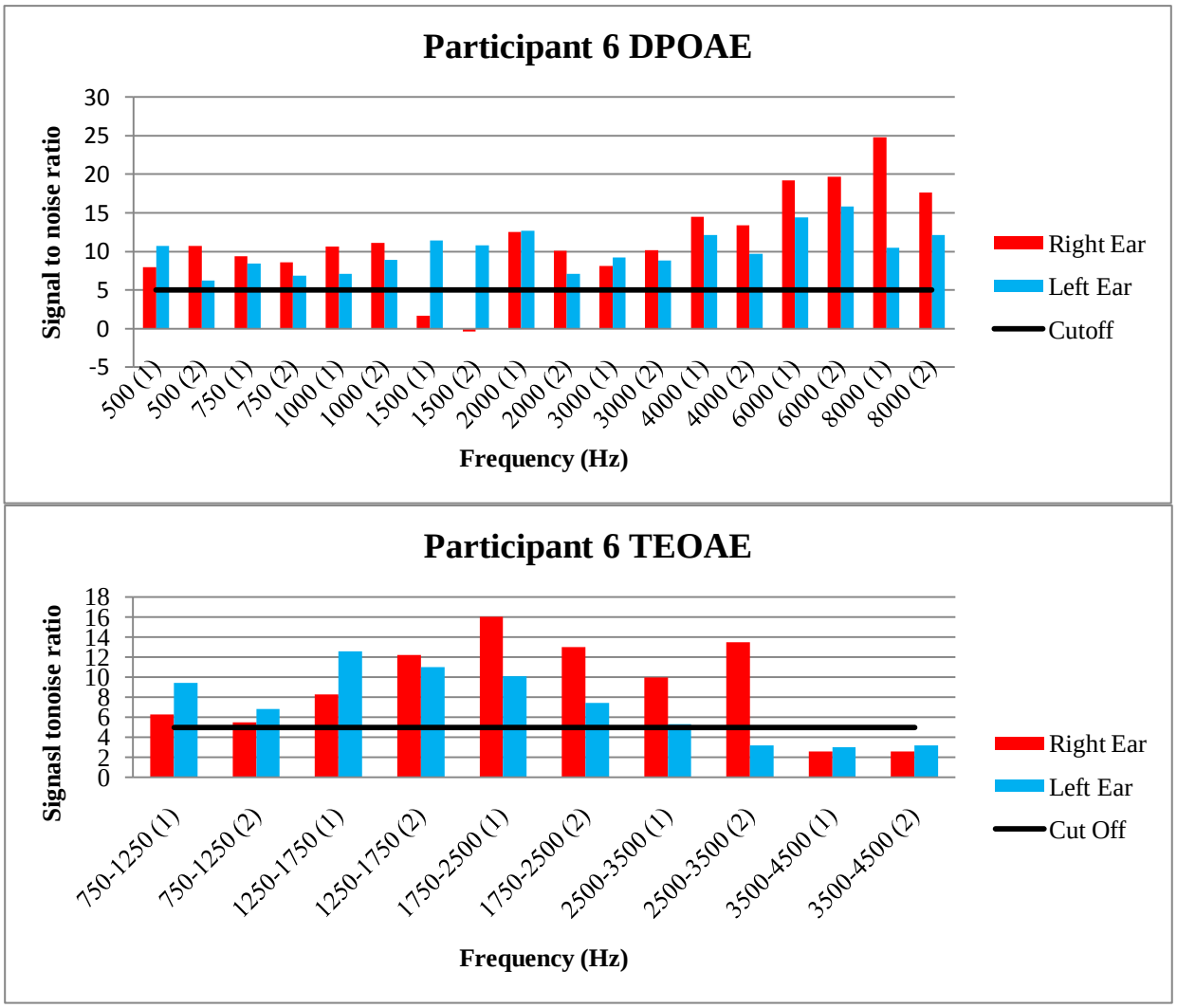

Figure 3.6: DPOAE and TEOAE recordings for participant

Participant 13:

Participant 13 is a 38 year old African male who sustained an intracranial hematoma affecting the temporal and frontal lobes, and received a GCS of 4. His basic audiological test results were all within normal limits. He was involved in a pedestrian accident, where he was knocked over by a car. He sustained speech, visual and auditory difficulties, of which only the visual difficulties have persisted. He also reported that his memory was affected, as he has many 'blanks' in his memory from before the incident. No tinnitus or vertigo was mentioned as a residual deficit from the closed head injury.

He failed the right DPOAE at 6000Hz and the left TEOAE at 750Hz-1250Hz, 1750Hz-2500Hz, 2500Hz-3500Hz and 3500Hz – 4500Hz. The results are displayed in Figure 3.7

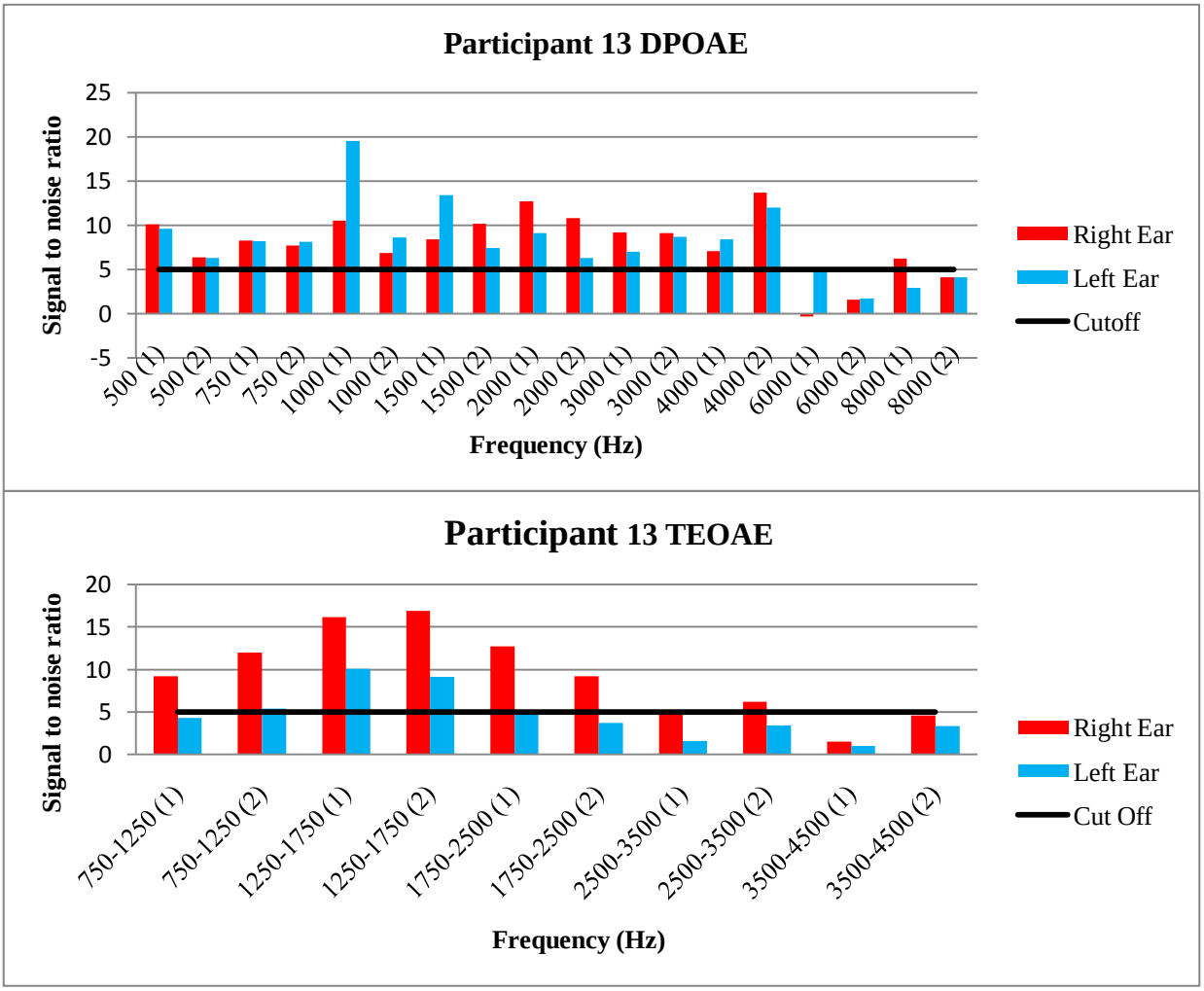

Figure 3.7: DPOAE and TEOAE recordings for participant 13

Participant 21:

Participant 21 is a 29 year old African male, who sustained an intracranial hematoma affecting the parietal and occipital lobes, and received a GCS of 4. His basic audiological test results were all within normal limits. He was knocked over by a truck and comatose for 21 days. He has no recollection of the incident, and therefore suffered from post traumatic amnesia. He reported that after the accident his speech was slurred and his hearing was affected, he also

experienced vertigo, but no tinnitus was reported. His hearing was reported to have returned to normal a few weeks after the incident.

He failed the right DPOAE at 3000Hz, 4000Hz, 6000Hz and 8000Hz, and the left DPOAE at 6000Hz and 8000Hz. He also failed the right TEOAE at 750Hz – 1250Hz, 1250Hz-1750Hz and 2500Hz – 3500Hz. The results are displayed in Figure 3.8

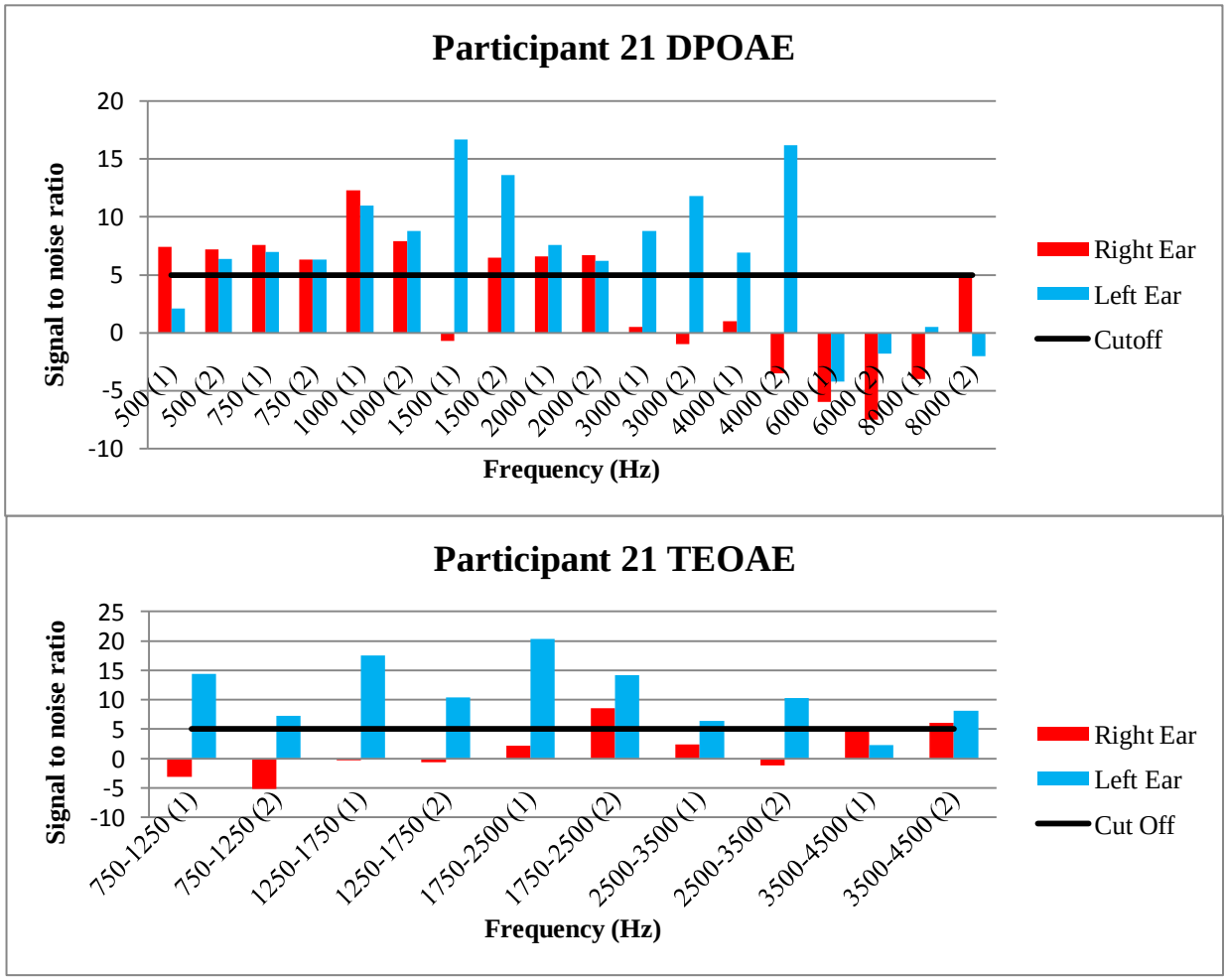

Figure 3.8: DPOAE and TEOAE recordings for participant 21

Participant 26:

Participant 26 is a 27 year old, white male, who sustained a concussion affecting the parietal and frontal lobes and received a GCS of 12. His basic audiological test results were all

within normal limits. He was reportedly kicked in the head by a horse; he does not remember the incident, therefore suffering from post traumatic amnesia; however his memory since the incident has been affected. He stated that the doctors told him that his eyesight and balance was affected, which did resolve quite soon after the injury. Vertigo was experienced for a short period after the incident, no tinnitus was experienced.

He failed the left TEOAE at 2500Hz – 3500Hz and 3500Hz – 4500Hz. The results are displayed in figure 3.9

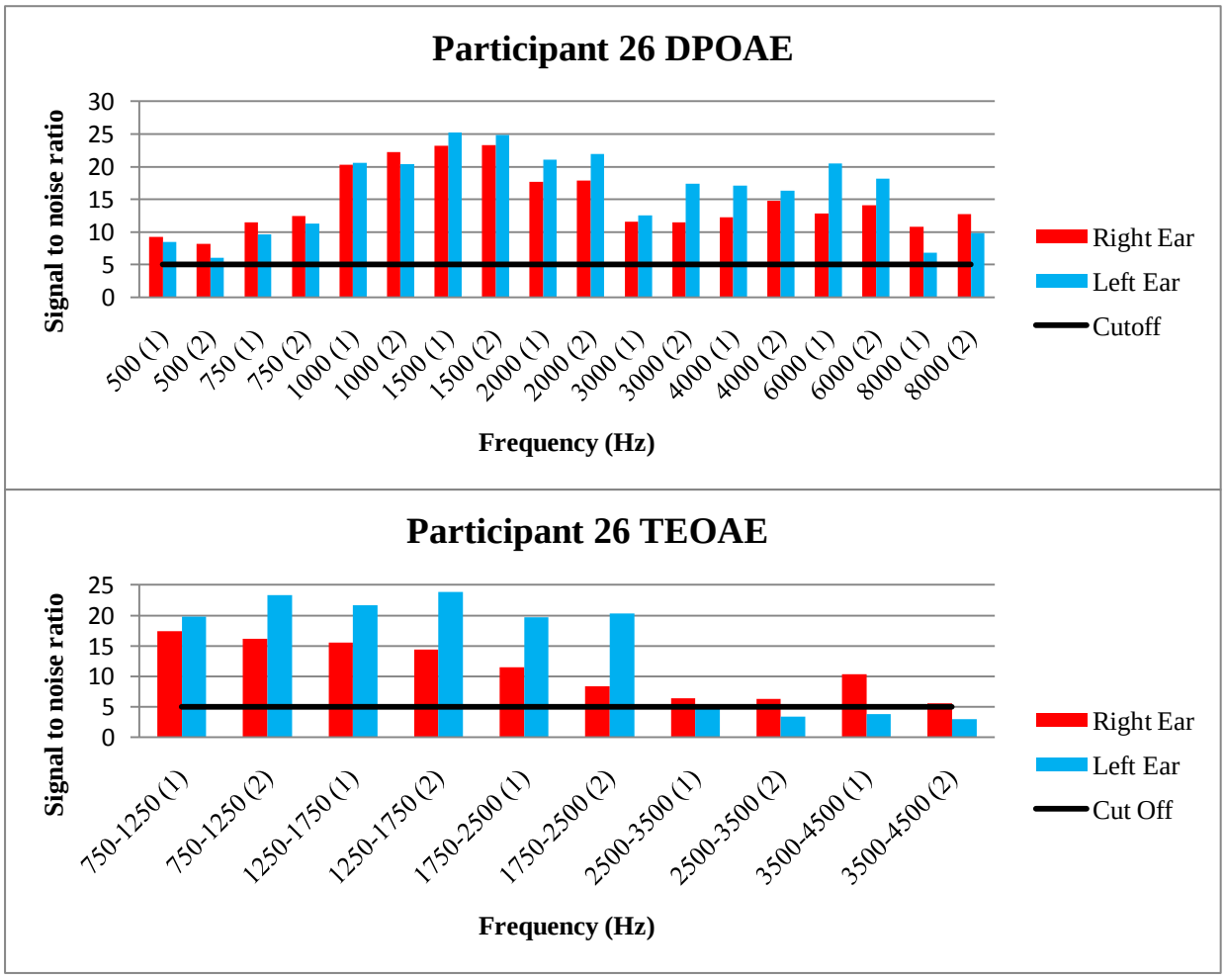

Figure 3.9: DPOAE and TEOAE recordings for participant 26

Participant 27:

Participant 27 is 28 year old, white male, who sustained a concussion of the left parietal and temporal lobes, and acquired a GCS of 13. His basic audiological test results were all within normal limits. He was involved in a poor rugby tackle after which he lost consciousness for a few minutes. He reported that he felt very dizzy and vertigo was experienced, his eyes were out of focus, his hearing was poor, he reported tinnitus in both ears for a few minutes after the accident, and his speech was affected. His difficulties were said to have all resolved about 5 hours after the injury.

He failed the right DPOAE at 6000Hz and the right TEOAE at 750Hz – 1250Hz, 1250Hz – 1750Hz, 1750Hz – 2500Hz, 2500Hz – 3500Hz as well as the left TEOAE at 2500Hz – 3500Hz and 3500Hz – 4500Hz. Figure 3.10 displays the OAE results of participant 27.

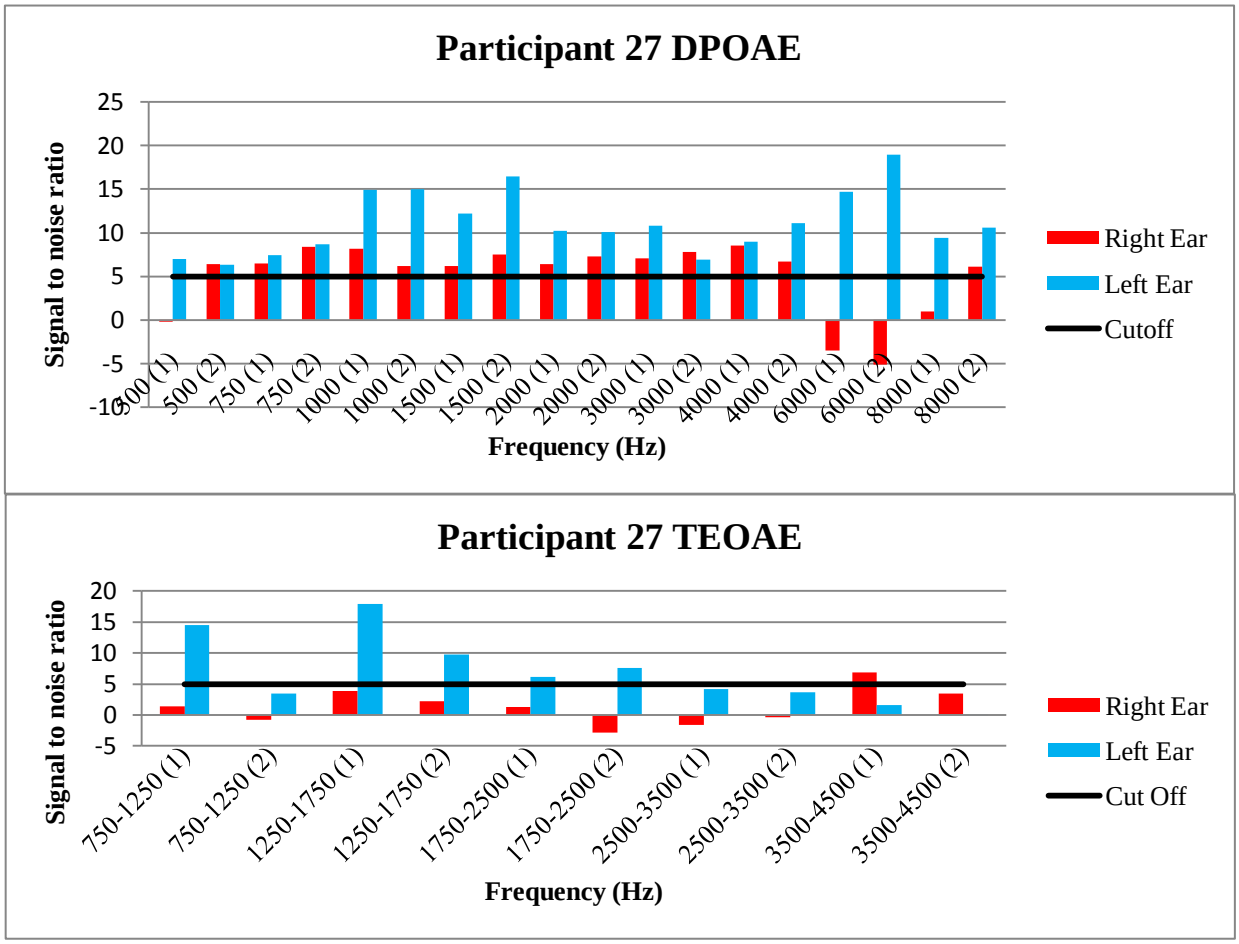

Figure 3.10: DPOAE and TEOAE recordings for participant 27

Only one participant (participant 26) failed the TEOAEs only on the left, whilst the remaining four participants had discrepancies on both the DPOAEs and TEOAEs.

Danielidis, Tsimpiris, Balatsouras, Polychronidis, Parente, Papadopoulos et. al. (2007), performed a study on rabbits (*N*=12) to identify OAE recordings following a closed head injury. These rabbits were divided into two groups of six, a control group (*N*=6) and an experimental group (*N*=6). The experimental group was subjected to mechanically enforced closed head injuries. Three hours following the closed head injury, the experimental group underwent OAE and ABR recordings. The results revealed abnormalities on both measures. However more

damage was seen on the ABR recordings. The OAE recordings presented with subtle abnormalities such as those presented in the OAE recordings of the current study, meaning that only a few frequencies out of the entire frequency range were compromised. However the ABR recordings revealed much more extensive damage along the auditory pathway, destroying a large amount of the auditory nerve, especially those involving wave V (Danielidis et. al., 2007). Findings from this study did reveal that the peripheral and central auditory system is affected three hours post CHI. The current study revealed that only 16% (5 participants) presented with OAE abnormalities, while the remaining 84% (25 participants) revealed no OAE deficits. These results are congruent with that of Danielidis et. al. (2007) study that abnormalities are detected on OAE results following a closed head injury, but not to such a large extent as to compromise all the outer hair cells along the OAE frequency range.

It is very interesting to note that all five participants who presented with abnormal OAE results were male. McFadden (2001) declared that OAE measures are similar to those of pure tone testing which favors women to men, meaning that women present with better hearing than men. In addition, Schmuziger et. al., (2005) reported that OAEs were found to be present and better in females than in males. If one analyzes the OAE results according to this information, then the results are congruent with these reports and display the same findings of female hearing reported to be superior to male hearing, even following a CHI (McFadden, 2001). However it is important to take into account the fact that there were 23 male participants as opposed to the seven female participants in the current study, therefore giving the males an increased advantage in presenting with OAE deficits. Regardless, it is still evident that the female participants presented with normal OAE recordings; even thought this finding should be interpreted with caution due to the identified sample limitation

3.2.2.2 *Auditory brainstem response*

Even in the early stages of a CHI, the use of ABR has been reported to be sensitive in identifying any type of pathology along to auditory system (Ratcliff et. al., 2007). With regards to the ABR in the current study two measures were conducted on each participant, namely a neurological ABR and an audiological ABR. All ABR recordings were recorded twice to ensure repeatability hence reliability of results.

Neurological ABR findings for all participants were analyzed according to six specific analysis steps which included examining the following:

a) Morphology of the ABR waveforms:

   ABR recordings obtained at higher intensities (e.g., 75dB nHL) should contain well-defined peaks, and the presence of at least Waves I, III and V for each ear" (Hood, 1998, p.24).

b) I/V amplitude ratio:

   Comparison between amplitudes of wave I and wave V, where wave V should be at least double the amplitude of wave I (Hall, 2007).

c) Repeatability of the ABR waveforms:

   The ipsilateral waveforms that are recorded twice at each intensity level must be repeatable within 0.2ms of each other, in order for the waveform to be considered a reliable recording (Hall, 2007).

d) Absolute wave latencies of waves I, III, and V:

   Absolute wave latencies refer to the actual time frame at which the particular wave occurs. For wave I the absolute latency is 1.65 ms with a SD of plus or minus 0.14

ms. Wave III must occur at 3.80 ms with a SD of plus or minus 0.18 ms. Wave V must occur at 5.64 ms with a SD of plus or minus 0.23 ms (Hall, 2007).

e) Interwave latencies of waves I-III, III-V and I-V.

Interwave latency recordings between wave I-III must be at 2.15 ms with SD of plus or minus 0.14 (Hall, 2007). Interwave latency between wave III-V must be at 1.84 ms with a SD of plus or minus 0.14 ms (Hall, 2007). Interwave latency between wave I-V must be at 3,99 ms with a SD of 0.20 ms (Hall, 2007).

f) Absolute latency difference of wave V.

The absolute latency difference of wave V between the left and right ears should be at 0.3/0.4 ms with a SD of plus or minus 0.11 ms (Hall, 2007).

Table 3.3 displays the means and SDs for the above six steps for both the first and second ABR tracings.

Table: 3.3 Description of means and SDs of wave morphology, wave repeatability, amplitude of waveforms, absolute wave latencies, interwave latencies, absolute wave V latency

Factor					
Morphology		80% (24 participants) displayed good waveform morphology. 17% (five participants 1, 13, 21, 26, 28) displayed questionable waveform morphology, and 3% (participant 15) displayed poor waveform morphology.			
Repeatability		Results of repeatability were the same as those recorded for waveform morphology, being 80% (24 participants) displayed good waveform repeatability. 17% (five participants, 1, 13, 21, 26, 28) displayed questionable waveform repeatability, and 3% (participant 15) displayed poor waveform repeatability.			
I/V Amplitude ratio		100% of the participants presented with I/V Amplitude ratio within normal limits. Kehrle et al, (2008) reported that wave V/I amplitude is only significant when wave V is half the size of wave I			
		Mean	**Norms**	**SD**	**Normal/Early/Late waveforms**
R AWL I	**Rec. 1**	1.536	1.65 (SD0.14)	0.095	normal
	Rec. 2	1.549	1.65 (SD 0.14)	0.100	normal
L AWL I	**Rec.1**	1.587	1.65 (SD 0.14)	0.064	normal
	Rec. 2	1.596	1.65 (SD 0.14)	0.066	normal
R AWL III	**Rec. 1**	3.711	3.80 (SD 0.18)	0.093	normal
	Rec. 2	3.682	3.80 (SD 0.18)	0.123	normal
L AWL III	**Rec. 1**	3.745	3.80 (SD 0.18)	0.122	normal
	Rec. 2	3.742	3.80 (SD 0.18)	0.120	normal
R AWL V	**Rec. 1**	5.376	5.64 (SD 0.23)	0.318	normal
	Rec. 2	5.376	5.64(SD 0.23)	0.300	normal
L AWL V	**Rec. 1**	5.453	5.64 (SD 0.23)	0.228	normal
	Rec. 2	5.427	5.64 (SD 0.23)	0.234	normal
R Inter I-III	**Rec.1**	2.178	2.15 (SD 0.14)	0.053	normal
	Rec. 2	2.161	2.15 (SD 0.14)	0.069	normal
L Inter I-III	**Rec. 1**	2.157	2.15 (SD 0.14)	0.615	normal
	Rec. 2	2.139	2.15 (SD 0.14)	0.055	normal
R Inter III-V	**Rec. 1**	1.773	1.84 (SD 0.14)	0.136	normal
	Rec. 2	1.811	1.84 (SD 0.14)	0.164	normal
L Inter III-V	**Rec.1**	1.803	1.84 (SD 0.14)	0.119	normal
	Rec. 2	1.816	1.84 (SD 0.14)	0.129	normal
R Inter I-V	**Rec. 1**	3.904	3.99 (SD 0.20)	0.146	normal
	Rec. 2	3.966	3.99 (SD 0.20)	0.247	normal
L Inter I-V	**Rec.1**	3.984	3.99 (SD 0.20)	0.198	normal
	Rec. 2	3.797	3.99 (SD 0.20)	0.519	normal
Interaural	**Rec. 1**	0.221	0 (SD 0.11)	0.300	normal
	Rec. 2	0.221	0 (SD 0.11)	0.300	normal

Key: R = right; L = left; AWL = absolute wave latency; Inter = interwave; SD = standard deviation; rec. 1 = recording 1; rec.2 = recording 2.

As seen in Table 3.3 the means of all waveforms were within normal limits (Hood, 1998; Hall, 2007), however when analyzing the neurological ABR recordings for each individual

participant, certain abnormalities were found for some participants. Participants with abnormal ABR findings included participant 6, 7, 9, 10, 11, 13, 14, 19, 21, 23, 24, 26, 27 and 30, as depicted in Table 3.4. A number of studies have identified abnormalities on ABR testing following a CHI (Abd Al-Hady et al., 1990; Greenberg, Newlon, Hyatt, Narayan, & Becker, 1981; Hall, Huang-fu, & Gennarelli, 1982). Table 3.4 highlights the participants with subtle irregularities from the neurological ABR recordings. The "subtle irregularities" which are identified within the ABR recordings, refer to early latencies. It is of interest to note that of the participants with subtle ABR abnormalities on the neurological ABR, five of them were the same participants with abnormal OAE findings (participants 6, 13, 21, 26 and 27)

Table 3.4 Participants presenting with subtle irregularities on the neurological Auditory Brainstem Response (ABR)

Participant Number	Wave Morphology	Wave Repeatability	Amplitude I/V	AWL (1)	AWL (2)	IWL (1)	IWL (2)	Interaural Wave V (1)	Interaural Wave V (2)
6	good	good	Wave V not Dbl wave I	L III (3.6) ∂				0.2	0.27
7	good	good	Wave V not Dbl wave I	R V (5.07) ∂	R V (5.07) ∂	R III-V (1.67) ∂	R III-V∂ (1.67)		
9	good	good	Wave V not Dbl wave I	R I (1.47) ∂ R III (3.53) ∂ R V (4.67) ∂ L I (1.47) ∂ L III (3.6) ∂ L V (5.4) ∂	R I (1.47) ∂ R III (3.53) ∂ R V (4.8) ∂ L III (3.53) ∂ L V (5.33) ∂	R III-V (1.53) ∂ R I-V (3.6) ∂	R III-V (1.67) ∂ R I-V (3.73)∂	0.73	0.53
10	good	good	Wave V is Dbl wave I	R V (5.2) ∂ L V (5.33) ∂	R V (5.13) ∂ L V (5.33) ∂	R III-V (1.67) ∂ L III-V (1.53) ∂	R III-V (1.6)∂ L III-V (1.6)∂	0.13	0.2
11	good	good	Wave V not Dbl wave I	R V (4.87) ∂ L V (5) ∂	R I (1.47) ∂ R V (4.93) ∂ L V (5) ∂	R III-V (1.53) ∂ R I-V (3.73)∂ L III-V (1.67) ∂	R III-V (1.67) ∂ L III-V (1.67) ∂		
13	quest	quest	Wave V is Dbl wave I	R I (1.33) ∂ R V(5.27) ∂ L I (1.47) ∂ L V (5.07) ∂	R V (4.87) ∂ L I (1.47) ∂ L V (5.07) ∂	L III-V (1.6)∂	R III-V (1.47) ∂ R I-V (3.33)∂ L III-V(1.67) ∂	0.46	0.8
14	good	good	Wave V is Dbl wave I	R V (4.67) ∂	R V (4.8) ∂ L III (3.4) ∂	R III-V (1.4)∂ R I-V (3.47)∂	R III-V (1.53) ∂ R I-V (3.67)∂	0.93	0.73
19	good	good	Wave V not Dbl wave I	R V (5.4) ∂ L V (5) ∂	R V (5.27) ∂	L III-V (1.53) ∂	L III-V (1.33) ∂	0.4	0.47

Table 3.4 Participants presenting with subtle irregularities on the neurological Auditory Brainstem Response (ABR)

					L V (4.8) ∂		L I-V (3.6) ∂		
21	R = quest L = good	R = quest L = good	Wave V is Dbl wave I					0.2	0.34
23	good	good	Wave V not Dbl wave I	R III (3.5) ∂ L III(3.53) ∂	R I (1.47) ∂ R III (3.47) ∂ R V (5.4) ∂ L III (3.53) ∂ L V (5.4) ∂			0.2	0.26
24	good	good	Wave V not Dbl wave I	R III (3.6) ∂ L III (3.53) ∂	R III (3.53) ∂ R V (5.47) ∂ L III(3.47) ∂				
26	R = quest L = good	R = quest L = good	Wave V is Dbl wave I	R I (1.27) ∂	R I (1.27) ∂ R III (3.33) ∂		R III-V(2.33) ∂ R I-V (4.4) ∂		0.2
27	good	good	Wave V not Dbl wave I	R V (4.87) ∂ L III (5.07) ∂	R V (4.93) ∂ L V (4.93) ∂	R III-V (1.53) ∂ R I-V (3.67) ∂	R III-V (1.6) ∂	0.2	
30	good	good	Wave V not Dbl wave I	R V (5) ∂ L I (1.47) ∂ L V (5.07) ∂	R V (5.07) ∂ L V (5.17) ∂	R III-V (1.67) ∂ L III-V (1.6) ∂	R III-V (1.67) ∂ L III-V (1.67) ∂		0.2

Key: R = right; L = left, W=wave AWL = absolute wave latency, IWL = interwave latency, (1) = first recording; (2) = second recording; I = wave I, III = wave III, V = wave V; Dbl = double, quest = questionable; ∂= early

Don, Ponton, Eggermont and Masuda (1993) reported that ABR waveforms are susceptible to gender differences. In the 1970s it was proposed that gender plays a significant role in accounting for hearing loss between the male and female population, as females were shown to have a smaller central nervous system (Ratcliff et. al., 2007) which was postulated as one of the reasons for ABR differences. This could account for the fact that women have shorter wave V absolute latencies (Kehrle et al., 2008). Therefore the fact that women and men appear to be anatomically different would lead to the 'assumption' (Kehrle et al., 2008, p 307), that auditory examination results may vary between the two genders; which may explain the current study findings. The current study's abnormal ABR findings could also be due to some sub-clinical peripheral hearing abnormality which also seemed to have had an influence on OAE results for the same participants. However the argument of gender differences in ABR recordings appears to hold truer in the current study than that of subclinical hearing changes.

Even though this information is relevant, gender differences relating to hearing loss is thought to be considered 'just an idea' (Ratcliff et al., 2007, p 205) and does not have any credibility, as many studies have consistently found evidence to deny this theory (Dunckley & Dreisbach, 2004; Bergemalm & Lyxell, 2005; Brown et.al., 2007; McFadden, 2008); and the current researcher's findings do not seem to advance the solution to this debate, mainly due to the sample gender distribution limitation acknowledged earlier.

The current findings revealed that gender does play a significant role with regards to ABR testing. This is congruent with the information provided by Don et al. (1993) and Ratcliff et.al. (2007). In a study conducted by Kehrle et.al. (2008) it was reported that women have shorter wave V absolute wave latencies, and this was found to be true for the current study as

many of wave V latencies appeared to be early in the ABR recordings of the seven women in the study. Table 3.5 indicates the ABR wave V latencies for the seven females who participated in the current study.

Table 3.5: ABR latencies involving wave V presented in the female participants (*N*=7)

Part. No.	AWL V First trace	AWL V (2)	IWL III-V (1)	IWL III-V (2)	IWL I-V (1)	IWL I-V (2)	Interaural V (1)	Interaural V (2)
1	R 5.53	R 5.4	R 1.87	R 1.87	R 3.80	R 4.03	R 0.06	R 0.07
	L 5.47	L 5.47	L 1.8	L 1.8	L 3.87	L 3.87		
9	**R 4.67** $^{\partial}$	**R 4.8** $^{\partial}$	**R 1.53**$^{\partial}$	**R 1.67**$^{\partial}$	**R 3.6**$^{\partial}$	**R 3.73**$^{\partial}$	**0.73**¶	**0.53** ¶
	L 5.4 $^{\partial}$	**L 5.33**$^{\partial}$	L 1.8	L 1.8	L 3.87	L 3.87		
10	**R 5.2**$^{\partial}$	**R 5.13**$^{\partial}$	**R 1.67**$^{\partial}$	**R 1.6**$^{\partial}$	R 3.93	R 3.80	0.07	**0.2** ¶
	R 5.33$^{\partial}$	**R 5.33**$^{\partial}$	**R 1.53**$^{\partial}$	**R 1.6**$^{\partial}$	R 3.93	R 3.93		
11	**R 4.87**$^{\partial}$	**R 4.93**$^{\partial}$	**R 1.53**$^{\partial}$	**R 1.67**$^{\partial}$	**R 3.73**$^{\partial}$	R 3.87	**0.13**¶	0.07
	L 5$^{\partial}$	**L 5**$^{\partial}$	**L 1.67**$^{\partial}$	**L 1.67**$^{\partial}$	L 3.87	L 3.87		
22	R 5.67	R 5.67	R 1.93	R 1.80	R 3.93	R 3.93	0	0
	L 5.67	L 5.67	L 1.93	L 1.93	L 4.07	L 4.13		
23	**5.47**$^{\partial}$	**R 5.4**$^{\partial}$	R 1.93	R 1.93	R 3.93	R 3.93	0	0
	L 5.47	**L 5.4**$^{\partial}$	R 1.93	R 1.87	R 3.93	R 3.87		
24	**R 5.47**$^{\partial}$	**R 5.47**$^{\partial}$	R 1.87	R 1.93	R 3.87	R 3.87	**0.2**¶	**0.26** ¶
	L 5.67	L 5.63	L 1.93	L 1.87	**L 4.33**$^{\partial}$	**L 4.33**$^{\partial}$		

Key: Part. No. = Participant Number; AWL = absolute wave latency; IWL = interwave latency; V = wave V, I = wave I; (1) = first recording; (2) = second recording; R = right; L = left; $^{\partial}$ = early; ¶ = Poor; Bold = abnormal results

As displayed in Table 3.5 above there appeared to be many early latencies recorded (bold indicates early latencies) in the female sub-sample. Additionally, poor interaural wave V latencies refers to the difference between the left and right ears which should be at 0.3/0.4 ms with a SD of plus or minus 0.11 ms (Hall, 2007), and if the interaural wave V latencies fall outside this norm, it is considered a 'poor' recording. This leads to the understanding that the fact that these women presented with early ABR wave V latencies could in fact be due to the documented fact that women tend to have shorter wave V latencies than men (Kehrle et.al. 2008). It therefore cannot be concluded that the poor wave V latencies found in the female sub-

sample reflects deficits in hearing due to the CHI, but may rather reflect the gender differences between ABR wave V recordings, which concurs reports in the literature.

Bergemalm and Borg (2001) reported that the most sensitive index which primarily reflects the central conduction time is the wave I/V amplitude index, and this aspect of the ABR should therefore be analyzed in depth. Table 3.6 displays the wave I/V amplitude index for participants in the current study.

Table 3.6: Amplitude I/V index (*N* = 30 participants)

Part. No.	R Ampl I/V (1)	R Ampl I/V (2)	L Ampl I/V (1)	L Ampl I/V (2)
1	V is smaller than I	V is smaller than I	V is smaller than I	V is smaller than I
2	V is smaller than I	V is smaller than I	V is smaller than I	V is smaller than I
3	V is smaller than I	V is smaller than I	V is smaller than I	V is smaller than I
4	V is smaller than I	V is smaller than I	V is smaller than I	V is smaller than I
5	V is smaller than I	V is smaller than I	V is smaller than I	V is smaller than I
6	V is bigger than I, but not Dbl	V is smaller than I	V is bigger than I, but not Dbl	V is smaller than I
7	V is bigger than I, but not Dbl	V is bigger than I but not Dbl	V is bigger than I, but not Dbl	V is bigger than I, but not Dbl
8	V is smaller than I	V is smaller than I	V is bigger than I, but not Dbl	V is bigger than I, but not Dbl
9	V is smaller than I	V is smaller than I	V is bigger than I, but not double	V is bigger than I, but not Dbl
10	V is twice as big as wave I	V is bigger than I but not Dbl	V is bigger than I, but not Dbl	V is bigger than I, but not Dbl
11	V is smaller than I	V is smaller than I	V is smaller than I	V is smaller than I
12	V is smaller than I	V is smaller than I	V is twice as big as wave I	V is smaller than I
13	V is smaller than I	V is twice as big as wave I	V is bigger than I, but not Dbl	V is bigger than I, but not Dbl
14	V is smaller than I	V is smaller than I	V is smaller than I	V is smaller than I
15	V is smaller than I	V is twice as big as wave I	V is smaller than I	V is bigger than I, but not Dbl
16	V is smaller than I	V is smaller than I	V is smaller than I	V is bigger than I, but not Dbl
17	V is bigger than I, but not Dbl	V is bigger than I but not Dbl	V is bigger than I, but not Dbl	V is bigger than I, but not Dbl
18	V is smaller than I	V is smaller than I	V is smaller than I	V is smaller than I
19	V is smaller than I	V is smaller than I	V is smaller than I	V is smaller than I
20	V is smaller than I	V is bigger than I but not Dbl	V is smaller than I	V is smaller than I
21	V is smaller than I	V is twice as big as wave I	V is bigger than I, but not Dbl	V is smaller than I
22	V is smaller than I	V is smaller than I	V is bigger than I, but not Dbl	V is smaller than I
23	V is smaller than I	V is smaller than I	V is smaller than I	V is smaller than I
24	V is smaller than I	V is smaller than I	V is smaller than I	V is smaller than I
25	V is smaller than I	V is smaller than I	V is twice as big as wave I	V is bigger than I, but not Dbl
26	V is bigger than I, but not Dbl	V is bigger than I but not Dbl	V is bigger than I, but not Dbl	V is bigger than I, but not Dbl

Table 3.6: Amplitude I/V index (N = 30 participants)

Part. No.	R Ampl I/V (1)	R Ampl I/V (2)	L Ampl I/V (1)	L Ampl I/V (2)
27	V is smaller than I	V is bigger than I but not double	V is smaller than I	V is smaller than I
28	V is smaller than I	V is bigger than I but not Dbl	V is smaller than I	V is twice as big as wave I
29	V is twice as big as wave I	V is twice as big as wave I	V is smaller than I	V is bigger than I, but not Dbl
30	V is bigger than I, but not Dbl	V is bigger than I but not Dbl	V is bigger than I, but not Dbl	V is bigger than I, but not Dbl

Key: Part. No. = participant number; R = right; L = left; (1) = recording 1; (2) = recording 2; Ampl = amplitude; V = wave V; I = wave I; Dbl = double

The wave I/V amplitude ratio should read that the wave V is twice as big as wave I (Hall, 2007). It is postulated that as wave V is closer to the auditory cortex where more stimulation/neural impulses occur. This would provide wave V with greater amplitude than wave I, which is situated closer to the cochlea and where there is less stimulation (Kehrle et. al., 2008).

When the aforementioned norm is adopted in the current study, it is apparent that in the right ear, only four participants (participants 10, 13, 15 and 21) present with wave V double the size of wave I. However Kehrle et al, (2008) reported that wave V/I amplitude is only significant when wave V is half the size of wave I. This was not apparent in the current study as Wave V appeared to be the same size or a little smaller than wave I, however they were never half the size, which according to Kehrle et al, (2008) renders the recording acceptable.

The audiological ABR provides an estimation of hearing thresholds. The results indicated that the estimated hearing thresholds for all participants (N=30) were within normal limits as tracings were recorded at 20dBnHL. This corresponds well with the basic auditory test results. Hearing thresholds were visible at 20dBnHL. From 20dBnHL it is assumed that hearing is within normal limits (Roger & Thornton, 2007). Even though some discrepancies were visible on the neurological ABR, the audiological ABR revealed normal audiometric thresholds, consistent with pure tone findings. It is asserted that the integrity of the hearing system may allow for flexibility, in that the hearing system itself may present with certain anomalies, however if not significant (as shown in the results of the 30 participants in the current study), hearing remains normal (Bergemalm et. al., 2009; Bergemalm, 2003; Collinson et al., 2009). However it must be taken into consideration that anomalies of the hearing system due to a CHI may lead to hearing difficulties at a later stage, and render the hearing system more susceptible

to deficits (Collinson et al., 2009). Bergemalm et al., (2009) and Bergemalm (2003) do report however, that a trauma to the head resulting in a fracture/open head injury, will have extremely severe consequences for the hearing system, and can cause permanent deafness/damage. CHI appear to 'shock' the hearing system, and therefore temporarily result in hearing damages, however due to the body's incredible healing abilities, the auditory system is able to return to normal once the 'shock' has dissipated (Bergemalm et al., 2009; Bergemalm, 2003); which may have been the case in the current study since testing occurred two years post CHI.

3.3 RELATING THE AUDIOLOGICAL FINDINGS WITH THE MEDICAL AND RADIOLOGICAL FINDINGS

The third sub-aim of this current study was to relate the audiological findings with the medical and radiological findings for adults with CHI.

3.3.1 Basic audiological tests which included the otoscopic examination, immittance measures, pure tone and speech results revealed hearing within normal limits for all participants (*N*=30). The implications of these results revealed that type of CHI, SOL and GCS score, does not appear to affect the hearing system. This finding relates to the literature which states that hearing loss is not evident as a long term deficit associated with a CHI (Bergemalm et. al., 2009; Bergemalm, & Borg, 2001; Bergemalm, 2003, Brown et. al., 2007). However the literature which presented this finding used basic hearing tests, and sometimes even psychiatrist's reports instead of audiologists (Brown et. al., 2007) to identify this finding. It should be noted that a more in-depth look at the auditory system using more advanced hearing tests revealed the presence of subtle abnormalities within a few of the participants hearing system.

3.3.2 OAEs revealed that when analyzing the mean results from all the participants (*N*=30), the sample presented with good outer hair cell functioning. These consequences confirm that the type of head injury, SOL and GCS scores does not appear to have any bearing on the hearing system functioning (refer to section 3.2.2.1, Figures 3.4 and 3.5). Nevertheless, when assessing the participants individually, it was found that five participants revealed subtle abnormalities on their OAE recordings (refer to section 3.2.2.1 Figures 3.6 to 3.10). Participant 6 sustained a concussion of the right temporal lobe, and received a GCS of 11; participant 13 sustained an intracranial hematoma involving the temporal and frontal lobes, and received a GCS of 4, participant 21 sustained an intracranial hematoma involving the parietal and occipital lobes, and received a GCS of 4; participant 26 sustained a concussion involving the frontal and parietal lobes and received a GCS of 12; participant 27 sustained a concussion involving the left parietal and temporal lobes and received a GCS of 13. These five participants who presented with abnormalities on their OAE recordings presented with differing SOL, different types of CHI and a varying recording on the GCS ranging from 4 to 13.

It is difficult to find a study which reports on the results of OAE recordings in CHI once the plateau of functioning (2 years post head injury) has occurred. A study conducted by Abd Al-Hady et. al., (1990) reported that OAEs are a good measure of prognosis in CHI patients. This study revealed that OAEs performed on patients with a CHI, soon after the injury would provide a relatively accurate detection of the patient rehabilitation recovery success. Failed OAE results were said to indicate poor prognosis, and passed OAE results would render a good prognosis and recovery. However this was not always the case, as there were a few participants with failed OAE results, who resulted in a good recovery. This research was conducted using screening OAEs, and a more in-depth analysis was not conducted. This research is beneficial for the

current study, due to the fact that both DPOAE and TEOAE results among the entire sample (*N*=30) revealed good OAE results, therefore it could be assumed that if OAE screenings were conducted on the participants at the time of their CHI, they would have passed the OAE screening, and a good prognosis would have been revealed. Most of the participants reported that their hearing systems were functioning normally, and were living 'normal' lives. On the other hand, Abd Al-Hady et. al., (1990) reported that this is not a 'rule' to identifying patient prognosis, as it was found that a few of the patients in their study with good OAE recordings, did not recover their functions. This may be the case with participant one of the current study, who presented with good OAE results and is in a wheelchair, has poor speech abilities, requires a caregiver to help her for 24 hours of the day as she is unable to move and is unable to function normally. Therefore it is important to look at a variety of tests, not only OAEs, but also tests involving cognition, visual, psychological etc, to be able to make a true diagnosis. This is also true for hearing assessments, as revealed in the current study, basic hearing tests alone do not provide an accurate diagnosis, and more advanced hearing tests must be performed so that the entire audiological system can be assessed accurately and a 'complete picture' of functioning can be identified.

3.3.3 Inferential statistics was used to analyze the results, which are presented using statistical analyses carried out by using the Statistical Package for Social Sciences (SPSS) version 13 (Howell, 1997). This section was aimed at establishing a relationship between the ABR and the medical findings which included type of CHI, SOL and GCS. The inferential statistics which included the Wilcoxon Matched Pairs Signed Rank Test and the Kruskal Wallis test examined the ABR recordings of absolute wave latencies, interwave latencies and interaural

latencies with the important medical and radiological variables of, gender, type of hearing loss, SOL and GCS scores. Significance levels were recorded when the *p*-value was < 0.05.

Table 3.7 displays the comparisons between the two recordings which include the minimum and maximum scores, the mean, SD and *p*-value for each tracing. The Wilcoxon test was utilized to statistically analyze the two recordings.

Table 3.7: Comparisons between the two recordings, including the minimum and maximum values, mean, SD and *p*-value: Wilcoxon test

ABR tracings		N	Minimum	Maximum	Mean	SD	*p*-value
R AWL I	tracing 1	30	1.27	1.73	1.5360	.09518	0.202
	tracing 2	30	1.27	1.80	1.5493	.10044	
R AWL III	tracing 1	30	3.50	3.93	3.7110	.09342	0.369
	tracing 2	30	3.33	3.93	3.6823	.12361	
R AWL V	tracing 1	30	4.67	5.73	5.3767	.31892	0.955
	tracing 2	30	4.8	5.7	5.376	.3003	
R IWL I-III	tracing 1	30	2.07	2.27	2.1783	.05395	0.421
	tracing 2	30	2.07	2.27	2.1617	.06919	
R IWL III-V	tracing 1	30	1.40	1.93	1.7733	.13700	0.084
	tracing 2	30	1.47	2.33	1.8110	.16411	
R IWL I-V	tracing 1	30	3.5	4.2	3.905	.1468	0.069
	tracing 2	30	3.33	4.87	3.9663	.24725	

L AWL I	tracing 1	30	1.5	1.7	1.587	.0648	0.380
	tracing 2	30	1.5	1.7	1.597	.0669	
L AWL III	tracing 1	30	3.53	3.93	3.7450	.12289	0.645
	tracing 2	30	3.47	3.93	3.7427	.12051	
L AWL V	tracing 1	30	5.00	5.80	5.4530	.22840	0.159
	tracing 2	30	4.80	5.73	5.4277	.23430	
L IWL I-III	tracing 1	30	2.00	2.27	2.1573	.06158	0.083
	tracing 2	30	2.07	2.27	2.1393	.05552	
L IWL III-V	tracing 1	30	1.5	1.9	1.803	.1194	0.216
	tracing 2	30	1.3	1.9	1.816	.1294	
L IWL I-V	tracing 1	30	3.80	4.93	3.9840	.19810	0.031*
	tracing 2	30	1.93	4.20	3.7977	.51952	
Interaural Wave V	tracing 1	30	.00	.93	.2217	.24663	0.871
	tracing 2	30	.00	.80	.2210	.23658	

Note: R = right; L = left; AWL = absolute wave latency; IWL = interwave latency
* significance at the 5% level

The *p*-value reports on a positive or negative relationship between the two recordings, meaning that if there is a major difference between the two recordings the *p*-value is expected to be less than 0.05. If this is the case, then it is confirmed that there was an abnormality with that waveform with regards to its functioning being either delayed, or early, as the two recordings are not showing similar results. As depicted in Table 3.6, all recordings except for one appear to have a positive relationship, meaning that both recording one and recording two present with similar results, and can therefore be seen as reliable. The recording which gave a negative

relationship and therefore implied a subtle abnormality in that waveform is shown to be on the left interwave I-V recordings, which gave a *p*-value of 0.031($p < 0.05$). Due to the findings that there is no relationship between recording 1 and recording two, only recording one was analyzed throughout the data set which included type of CHI, SOL and GCS. However due to the negative relationship between recording one and recording two of the left interwave I-V recording, both recording one and recording two of the left interwave I-V recordings were analyzed against the remaining data of type of CHI, SOL and GCS scores.

Type of CHI sustained is an important variable as stated in the introduction section, there are four types of CHI ranging from a mild concussion to a more severe intracranial hematoma, therefore it is essential to assess whether or not ABR recordings which include the absolute wave latencies, interwave latencies and interaural wave latencies, are degraded when associated with more severe CHI. Table 3.8 displays whether type of CHI has an effect on the ABR recordings of the 30 CHI participants. The Kruskal Wallis test was used to analyze this data.

Table 3.8: ABR recordings affected by type of CHI with regards to *p*-value scores

ABR recording	*p*-value (<0.05)
Right absolute wave latency I	0.094
Left absolute wave latency I	0.978
Right absolute wave latency III	0.429
Left absolute wave latency III	0.804
Right absolute wave latency V	0.210
Left absolute wave latency V	0.840
Right Interwave latency I-III	0.478
Left interwave latency I-III	0.266
Right Interwave latency III-V	0.471
Left interwave latency III-V	0.640
Right interwave latency I-V	0.257
Left interwave latency I-V (first recording)	0.430
Left interwave latency I-V (second recording)	0.759
Interaural wave V latency	0.661

Table 3.8 displays whether any type of CHI will result in a significant abnormality on the ABR recordings of both the right and the left absolute wave latencies, interwave latencies and the interaural wave V latency. Table 3.7 confirms that there is a negative relationship between type of CHI and ABR recordings (p-value > 0.05); meaning that the type of CHI sustained will not have any affect with regards to any abnormality on the ABR recordings in the current sample. Within the current study, hearing loss was not diagnosed regardless of the presence of any of the four types of CHI, and results appeared to vary from one patient to the next, despite the type of CHI that was incurred. No studies have been found which relate the type of CHI with a hearing loss, and most reports discussed CHI as a whole, and did not divide the results into the four different types of CHI. This lack of information could be due to the fact that no significant evidence exists between the types of CHI and its association with hearing deficits.

Appendix K includes Table 3.8 as well as information such as the number of people in the current study who sustained those particular types of CHI, the mean, SD and p-value (0.05).

GCS is another important variable as it is necessary to identify whether or not a lower GCS score has any effect on ABR recordings. Table 3.9 shows the ABR recordings affected by GCS scores with regards to p-value scores. The Kruskal Wallis test was used to statistically analyze these results.

Table 3.9: ABR recordings affected by GCS scores with regards to *p*-value scores

ABR recording	*p*-value (0.05)
Right absolute wave latency I	0.521
Left absolute wave latency I	0.612
Right absolute wave latency III	0.206
Left absolute wave latency III	0.826
Right absolute wave latency V	0.105
Left absolute wave latency V	0.067
Right Interwave latency I-III	0.034*
Left interwave latency I-III	0.409
Right Interwave latency III-V	0.475
Left interwave latency III-V	0.264
Right interwave latency I-V	0.047*
Left interwave latency I-V (first recording)	0.775
Left interwave latency I-V (second recording)	0.173
Interaural wave V latency	0.780

* significance at the 5% level

Table 3.9 indicates that all the wave latencies except for two revealed negative results (*p*-value > 0.05), however the positive results for the right interwave I – III tracing 1(*p*-value = 0.034 < 0.05), and the right interwave I – V tracing 1(*p*-value = 0.047 < 0.05) indicated that GCS may have in fact caused subtle abnormalities on these particular waveforms in the current sample. This information is not substantial enough to lead to an apparent deficit; however it does provide relevant information on the integrity of the auditory system, and therefore should be analyzed further.

Appendix L is a comprehensive table of the GCS and *p*-value scores, and presents the average differences, in the ABR, across the three levels of the GCS being: severe (a score of less than or equal to eight), moderate (a score of between nine to 12) and mild (a score between 13-15) (Ponsford et. al., 2004; Perel et. al, 2005). Appendix L includes data such as GCS score and their statistical relation to the different ABR recordings of both the right and the left absolute wave latencies, interwave latencies and the interaural wave V latencies. It also includes the

number of partcipants in the current study who received those particular GCS scores, as well as the mean, SD and *p*-value (<0.05).

With regards to SOL and audiological tests within the current study, the results were similar to those acquired from the comparison of findings to the type of CHI in that there was no pattern identified to indicate that a particular SOL will affect hearing function. In fact as a whole the participants revealed good hearing abilities, and did not appear to have deficits in hearing, even when the temporal lobe, which houses the function of hearing, was involved. This result could be due to the documented possible hearing system flexibility, which allows for the ability of the hearing system to heal itself and recover following a CHI (Bergemalm et. al., 2009; Bergemalm, 2003). Nevertheless it was important to analyze SOL as it may have some effects on the ABR waveforms, meaning that SOL may determine an abnormality on particular wave latencies. Appendix M displays the detailed results of the associations between SOL and ABR recordings which include absolute wave latencies, interwave latencies and interaural wave latencies, however no inferential statistical test could be performed on the SOL, as some sites of lesion have only one value, which leads to no variation, therefore the table indicates the ABR recordings, the different SOL, how many participants acquires damage to those particular SOL, the mean and the SD.

Nevertheless, from the results obtained in section 3.1 (Figure 3.2) it was confirmed that SOL did not appear to have any effect on hearing loss in the current sample, and it can therefore be assumed that SOL will not present any abnormalities on the ABR wave latency recordings.

It is therefore concluded that the inferential statistics in the current study revealed few subtle abnormalities with regards to the ABR recordings and their relation to medical and radiological

findings. The subtle abnormalities that were detected was that the GCS scores may affect both absolute wave latencies and interwave latencies and provide some abnormalities for the right interwave I-III tracing 1 at a *p*-value = 0.034 (< 0.05) and the right interwave I-V tracing 1 at a *p*-value = 0.047(< 0.05). This information is interesting, as GCS scores are used to determine patient prognosis and recovery, and if found to be low it may indicate other anomalies. This is visible on the ABR recordings. Even though it is subtle, it can be inferred that GCS scores are a good source of patient prognosis, and further investigation must be conducted to ensure the correct form of rehabilitation and treatment can proceed. Furthermore the results indicate that SOL and type of CHI did not have a direct effect on the auditory system within CHI patients in the current study, however the GCS scores are able to provide prognostic information.

3.4 TO DETERMINE THE OCCURRENCE OF HEARING LOSS WITHIN THE CHI POPULATION

The fourth sub-aim of the current study was to determine the occurrence of hearing loss within the CHI population.

This sub-aim directly relates to the main aim of the study which is to describe auditory functioning within the adult CHI population of South Africa.

Prior to determining the occurrence of hearing loss within the CHI participants within the current study, it is necessary to identify the symptoms associated with the CHI. Figure 3.11 displays the total deficits experienced by all of the 30 participants, note: the deficits are not mutually exclusive

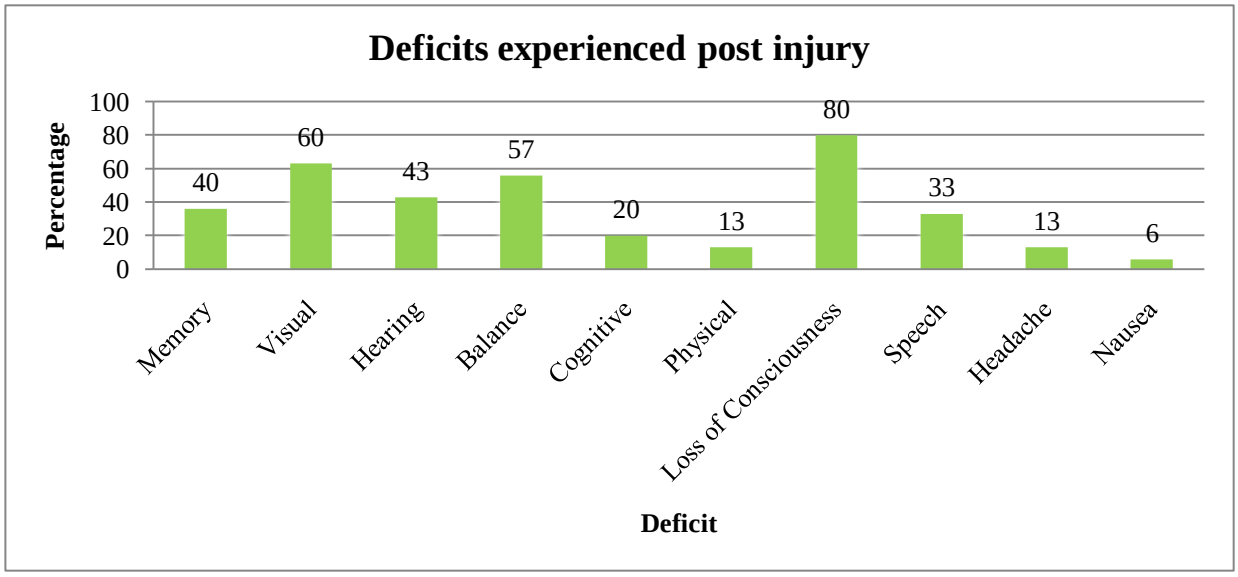

Figure 3.11: Deficits experienced by the participants, post CHI

The associated symptoms presented by the 30 participants once they acquired a CHI was reported as (i) loss of consciousness that was experienced by 24 participants (80%); (ii) 18 participants (60%) experienced visual and ocular deficits which included blurred vision, and inability to focus; (iii) 17 participants (57%) experienced balance and dizziness difficulties; (iv)13 participants (43%) experienced hearing deficits; (v) 12 participants (40%) experienced memory deficits; (vi) 10 participants (33%) experienced some sort of speech difficulty such as slurred speech, slow speech, poor word finding deficits; (vii) six participants (20%) experienced cognitive deficits; (viii) four participants (13%) experienced some sort of physical deficit such as paralysis, slow movements, inability to use hands, arms, difficulty with walking and moving around; (ix) four participants (13%) experienced headaches after incurring the closed head injury

(CHI); and (x) 2 participants (6%) experienced nausea after the CHI. Table 3.10 displays deficits experienced by each participant.

Table 3.10 Individual participant deficits following the CHI

Part. No.	Memory	Visual	Hearing	Balance	Cognitive	Physical	Loss of Consciousness	Speech	Headache	Nausea
1	✓				✓	✓	✓	✓		
2		✓		✓			✓			
3		✓	✓	✓			✓			
4		✓	✓				✓			
5		✓		✓			✓			
6	✓	✓					✓	✓		
7							✓		✓	✓
8			✓	✓			✓			
9					✓			✓		
10		✓	✓	✓			✓	✓		
11		✓								
12	✓				✓		✓		✓	✓
13	✓	✓	✓					✓		
14	✓			✓			✓			
15		✓				✓		✓		
16			✓			✓	✓	✓	✓	
17	✓	✓	✓				✓			
18				✓			✓			
19	✓		✓	✓						
20	✓	✓	✓		✓		✓		✓	✓
21	✓		✓	✓			✓	✓		
22						✓	✓	✓		
23		✓		✓			✓			
24		✓	✓	✓			✓			
25		✓		✓			✓			
26	✓			✓						
27		✓	✓	✓			✓	✓		
28	✓	✓		✓	✓		✓			
29	✓	✓	✓	✓	✓		✓			
30		✓		✓			✓			
Total	**12**	**18**	**13**	**17**	**6**	**4**	**24**	**10**	**4**	**3**
%	**40%**	**60%**	**43%**	**57%**	**20%**	**13%**	**80%**	**33%**	**13%**	**10%**

Key: Part. No. = participant number

Interestingly as depicted in Table 3.10 most deficits experienced by the participants were reported to have resolved within a few hours after the CHI; however some participants revealed that certain difficulties persisted to the present day. Participant 13, 14, 19, 21, 26 and 29 reported residual memory deficits; participant 15 and 21 reported residual speech deficits such as slurred

and slow speech, as well as word finding difficulties; participant 15 and 16 reported residual physical deficits (participant 15 walks with a limp and has limited movement in his right shoulder, participant 16 requires a walking stick); participant 15 reported residual visual difficulties; participant 16 and 20 reported that they suffer from headaches since the CHI; participant 20 and 29 reported residual cognitive deficits (participant 20 is unable to process numbers, participant 29 revealed that his processing is slow since the CHI); participant 20 suffers from nausea since the CHI. Table 3.11 identifies the participants with persistent residual deficits since their CHI and what the remaining deficits are.

Table: 3.11: Deficits remaining after the CHI for specific participants

Participant Number	Residual deficits
13	Memory deficits
14	Memory deficits
15	Speech, physical and visual deficits
16	Physical deficits and constant headaches
19	Memory deficits
20	Cognitive deficits, nausea and headaches
21	Speech and memory deficits
26	Memory deficits
29	Memory and cognitive deficits

With regards to the current study it is very important to note that although 43% of the participants complained of hearing deficits at the time of the CHI, on analyzing the data to determine the occurrence of hearing loss within the sample, no one presented with hearing loss as determined by basic audiological measures. The hearing deficits were reported by participants to have resolved a couple of days, hours or seconds following the CHI. The finding of lack of significant hearing deficits in the current investigation is very interesting as it may indicate that

temporary hearing difficulties and auditory processing may also be a contributing factor to the presence of a hearing loss.

All participants who were reported to have residual deficits (See Table 3.10) were all males. Ratcliff et. al. (2007) reported that progesterone contains neuroprotective components which aids in protecting and/or rebuilding the blood brain barrier. Women therefore appear to recover faster and their recovery is generally more substantial than that of men (Perel et. al., 2005). This finding from literature seems true in the current study as persistent deficits were reported by male participants two years post head injury.

From the results obtained for the previous sub-aims, it is evident that when examining the auditory system in the CHI participants in the current study, hearing loss is not identified. However, even though basic auditory test results reveal no hearing deficits, and the majority of the ABR tests reveal no statistically significant results, it is interesting to note, that OAEs were poor in 16.7% (5 participants) of the participants in this current study, and when analyzing the ABR data individually, discrepancies were found to occur along the auditory pathway in 47% (14 participants) of the participants.

This data is highly important as Brown et. al., (2007) reported that audition is not an essential area to assess following a CHI. This was diagnosed in their study by a psychiatrist (not a qualified audiologist) who was able to make this distinction however it was not shown how the psychiatrist came to this conclusion as no formal tests were available or presented in the study. In conclusion, the psychiatrist revealed that auditory deficits were uncommon in the CHI population. In addition, Bergemalm et. al. (2009) study concluded that in most of the cases, hearing impairment in CHI is mainly temporary and tends to dissipate during the post-traumatic

period. They also reported that the patient may believe that they have some sort of hearing loss, especially in more complex situations, but is closely related to symptoms of the "King-Kopetsky syndrome.

Wennmo and Svensson, (1989) did report that hearing loss is a deficit to a CHI with both skull fractures and without, Collinson et. al., (2009) reported that it is common for the CHI patient to suffer a gross auditory impairment. Podoshin and Fradis, (1975) reported that most of the hearing deficits seen in the CHI population will subside within the post-traumatic period; nevertheless, some have shown to persist and even progressively get worse.

This knowledge of possible hearing impairment associated with a CHI, appeared to be taken very lightly, as many studies involving CHI patients, assessed many areas of their residual functioning after the incident from psychological, neurological, cognitive, visual, speech and language, ocular and motor, yet audition was not assessed appropriately, but appeared to have been purely mentioned as an afterthought. It is interesting to note the study conducted by Youse and Coelho (2009) who reported that it is well documented that individuals with CHI have difficulty with conversational discourse. They provided a training and learning skills programme yet hearing was not assessed prior to the study. The study revealed poor outcomes for the ability to develop and manage appropriate content for their conversations, as well as to perceive the informal needs of the listener resulting in inappropriate responses, poor topic maintenance, and often resulted in tangential and irrelevant information. Nevertheless, even with these findings, Youse and Coelho (2009) still did not identify that lack of normal hearing function and/or auditory processing difficulties may play a part in the poor results obtained from their study.

Additionally when dealing with people who have suffered a CHI, it must be taken into account that the presence of a hearing loss may be due to a central auditory processing disorder (CAPD). As reported by Sinninger and Starr (2001), presentation of a CAPD may be misdiagnosed peripheral hearing loss, due to the specific features of CAPD which include: difficulty hearing and /or understanding in the presence of background noise; difficulty understanding muffled speech, accents or rapid speech; difficulty following verbal instructions; difficulty identifying and discriminating speech sounds; inconsistent responses to auditory information; repeatedly asking for repetition; poor listening skills; poor auditory localization skills; discrepancy between verbal versus written performance; use of a loud voice; being frightened or upset by loud noises, and possibility of having poor social skills. Behaviourally, people with CAPD present with hyperactivity/hypoactivity, they are usually 'loners'; they suffer from a poor self-concept; and they are reluctant to try new tasks due to fear of failure and are emotionally stretched (Sinninger & Starr, 2001). CAPD can be misdiagnosed as a hearing deficit, however it is a processing deficit, where the mechanism of hearing is intact, however the processing of the sounds is where the difficulty arises, in that there is miscommunication between the brain and the sounds heard (Sinninger & Starr, 2001).

It is therefore highly important to test head injured patients for CAPD using behavioural tests which can assess the central auditory nervous system such as, auditory evoked potentials, brainstem response testing including middle and late response testing (including P300) as well as using dichotic listening tests (Bellis, 1997).

Mignon, Schminky, Jane and Baran (2000) reported that hearing deficits experienced by CHI patients are most likely to be a consequence of a CAPD than a true impairment of the

hearing system itself. This claim is however disputed by Bergemalm (2009) who reported that CAPD is unlikely to be a consequence of a CHI, nonetheless pure tone testing alone will not provide this type of information. The fact that 43% of participants reported that their hearing returned to normal within a few days of the incident may relate to the fact that a CAPD may have occurred and resolved, rather than damage to the actual auditory pathways.

Despite the fact that the the central auditory nervous system (CANS) to be damaged by a head injury, the possibility of hearing loss in head injuries is generally overlooked (Bergemalm & Lyxell, 2005). Structural lesions associated with head injuries can directly impact upon and potentially disrupt the CANS (Meyers, Roberts, Bayless, Volkert, & Evitts, 2002). In some cases, the neural injuries are assessed using brain imaging technology, however imaging techniques and medical procedures often fail to detect the neural damage (Kaipio et. al., 2000; Musiek, Baran, & Shinn, 2004), suggesting that auditory testing of patients with minor head injuries should be conducted even in the absence of radiological evidence on brain imaging procedures.

Dichotic listening tests are the most widely used CAPD tests, used to determine a CANS involvement in head injured patients. Richardson, Springer, Varney, Struchen, and Roberts (1984) recommended that routine examinations conducted on head injured patients should always include the use of dichotic testing. Bergemalm and Borg (2001) found that 24% of patients with traumatic brain injury (TBI) failed a distorted (interrupted) speech test and 4% of patients failed a phase audiometry (interaural time difference) test at seven to 11 years after their injury. Meyers et. al. (2002) reported 100% specificity and 60% sensitivity for mildly brain-injured patients and 80% sensitivity for more severely brain-injured patients using a dichotic

speech test (Dichotic Word Listening Test). Early identification of a CAPD, is crucial at improving the patient's overall functioning in the cognitive and social domains, auditory processing abilities, and overall quality of life (Bergemalm & Lyxell, 2005). A limitation of the current study was that CAPD tests did not form part of the test battery, but an implication for future research has consequently been raised.

For a full examination of the patient who presents with a CHI it is essential that all areas of functioning be assessed, from cognitive to physical functioning, to emotional and psychological as well as testing one's hearing. However, it appears that the use of more advanced hearing tests should be conducted such as OAE testing, ABR testing, as well as tests for CAPD, so that the entire picture of patient functioning can be properly assessed, for full understanding of the patients' abilities, which in turn will affect rehabilitation methods and therapy following the CHI.

The current study clearly displayed the fact that basic hearing tests alone are not sensitive enough to provide a full diagnostic picture of the auditory system, and hearing may in fact appear to be intact for a number of CHI participants. Arlinger (2003) did report on the negative effects that a hearing loss can display on an individual's life, if left untreated. From the current study, many of the participants demonstrated deficits in hearing on the OAEs, and ABRs were irregular in the majority of the participants. It is therefore highly important that an individual who has sustained a CHI, should have the right to have their hearing assessed, just as well as the other components of their functioning, so that a full diagnostic picture can be determined, and the individual can attain a complete and educated understanding of their residual abilities, which may help them cope in the future. It is also very necessary to give them the opportunity to

understand the integrity of their hearing system following the CHI, in order for them to avoid situations which may have further, negative implications on their hearing, and promote better hearing conservation. As stated by Mellergard and Mathiesen, (1998) hearing loss associated with a head injury may alter one's life forever.

CHAPTER 4: CONCLUSION AND RECOMMENDATIONS

The current chapter offers conclusions to the current study by providing a summary of results from the current study in relation to the main aim of the study that examined the presence of hearing loss in the closed head injured population of South Africa; two to five years post injury. This chapter further provides a detailed critical evaluation of the study process including the consideration of the limitations of the study. Finally, clinical implications are presented and recommendations made for future research.

4.1 Summary of main findings:

- Basic hearing tests which included the otoscopic examination, immittance measures, pure tone and speech testing revealed normal hearing in all 30 closed head injured participants.
- The results of the OAEs were normal in 25 participants (83%). This reflects intact cochlea outer hair cell functioning (Debonis & Donohue, 2004); and is consistent with the basic audiometry findings.
- However when analyzed individually OAE revealed that 5 participants (17%) presented with OAE abnormalities on either the distortion product OAE, the transient evoked OAE or both.
- The neurological ABR revealed abnormalities on 14 participants (47%) neurological ABR recordings. They included the seven women in the sample, which as literature states, women have shorter wave V absolute latencies. Nevertheless it is important to

document that almost half of the sample of the closed head injured participants presented with subtle abnormalities on their neurological ABR recordings.

- All audiological ABR recordings were found to be normal and correlated well with the basic auditory tests which specifically related to pure tone testing between the 2000Hz and the 4000Hz region.
- Wave I/V amplitude where wave V was twice the size of wave I was seen on only four participants (13.3%) neurological ABR recordings however the remaining recordings were still seen as being within normal limits.
- The current study revealed that type of CHI whether mild or severe such as concussion, brain contusion, diffuse axonal injury and intracranial hematoma will not have a direct negative effect on hearing in the CHI population.
- The current study revealed that SOL where the CHI occurred, involving the frontal, temporal, occipital and parietal lobes will not be associated with a hearing loss in the CHI population.
- The current study revealed that the GCS scores which range from mild (13 – 15), moderate (9 -12) and severe (</= 8) will not provide negative consequences for the auditory system in the CHI population. However statistical analysis did reveal that GCS score may indicate a subtle abnormality along the auditory pathway, but was not significant enough to warrant a hearing loss.
- All participants experienced deficits following the CHI which involved functions such as memory, visual, hearing, speech and balance; cognitive and physical abilities; and loss of consciousness, headaches and nausea.

- Only nine participants (30%) of the sample experienced persistent deficits, the remaining 21 participants (70%) reported that their deficits subsided or dissipated within a few minutes, hours, days or months following the CHI.
- The current study reported that a hearing loss may not be diagnosed by the hearing tests especially basic hearing tests, however subtle abnormalities are visible on the more advanced tests of auditory integrity which include OAEs and ABRs.
- Hearing impairment following CHI is mainly temporary and tends to dissipate during the post-traumatic period.

Literature reviewed for the current study revealed that a large number of CHI are acquired every year world-wide (Jennett & McMillan, 1981; Naugle, 1990; Heitger et. al., 2006; Brown et. al,, 2007; Odebode et. al., 2005). Many examinations take place following a CHI to analyze complications that may occur following injury, and these have included cognitive evaluations, neurological, psychological, speech and language evaluations, ocular, visual and motor examinations. It is clear from the literature reviewed that only on occasion are auditory examinations conducted, revealing that auditory status appears to not be seen as an important part of a CHI diagnosis. The basic auditory tests that are conducted may also overlook certain auditory deficits. More advanced hearing tests such as OAEs and ABRs are required to provide a better understanding of the integrity of the auditory system following a CHI (Brown et. al., 2007). The reason for the lack of auditory intervention may be due to the fact that previous research and literature has reported that if a hearing loss is present after a CHI, it is mainly temporary and tends to dissipate during the post-traumatic period (Bergemalm et al., 2009). Furthermore a suspected hearing loss following a CHI may be due to the “King-Kopetsky” syndrome (Bergemalm et. al., 2009). Furthermore Mignon et. al.,

(2000) reported that the presence of a hearing loss following a CHI may be due to a CAPD, where the brain and the auditory system lack co-ordination and therefore are unable to link the actual sounds heard with the brains ability to process/perceive the sounds. Bergemalm et al. (2009) reported that is common for a CAPD to be a consequence of a CHI, and the ABR test may reveal abnormalities even in the early stages following the CHI. Furthermore it is likely for a CHI patient to present with normal basic hearing test results, however when hearing is tested in more complex listening situations such as in the presence of background noise, difficulties in hearing tend to arise.

In the current study it is evident that basic hearing testing revealed normal results and no abnormalities were detected, results which are congruent to those documented in the literature (Bergemalm & Borg, 2001; Bergemalm, 2003; Bergemalm & Lyxell, 2005; Brown et. al, 2007). Even though the literature reported that hearing loss is not a long term sequalae of a CHI, the studies conducted on this topic utilised only basic hearing tests which included pure tone testing and immittance testing, therefore the results obtained were similar to those obtained on the basic hearing tests within the current study. Nevertheless the tests of auditory integrity were not commonly used in previous studies, and the current study did reveal certain abnormalities within the OAE measures and along the auditory pathway in the ABR tests. This information is highly significant as it highlights the fact that in-depth deficits along the auditory system may in fact occur following a CHI.

4.2 Limitations of the study:

Although findings from the current study may contribute to developing a more particular audiological examination in the closed head injured population, these results need to be considered in light of the following weaknesses which serve as limitations to the study:

- The sample of participants for the current study was felt to not represent the South African population and only includes the African and Caucasian individuals. Although it is not expected that audiological findings will be influenced by race, it is recommended that future studies include more racial and linguistic diversity for better representation of the South African context. Furthermore, future studies should also include participants from various rehabilitative facilities across the country to increase generalizability of findings.
- The current study sample included more male participants (77%) to female participants (23%). It is therefore recommended that an equal number of male to female closed head injured participants should be recruited for future studies so that a more accurate picture about hearing loss can be identified among the two genders.
- Participants should be distributed more equally between the age groups to determine if a relationship between hearing loss among the closed head injured population across the age groups exists. Within the current study, the majority of the participants (50%) were between the ages of 20-29 years old.
- Due to the location of the testing booths being situated at the University of the Witwatersrand, a large sample size could not be recruited as many participants were not

able to participate as they resided quite a distance from the university grounds. The small sample size has an influence on generalizability of findings.

- More advanced tests of auditory integrity must be conducted which include middle latency response testing, late latency response testing, P300 testing, as well as tests of CAPD which include dichotic listening tests for a more holistic audiological profile to be established in this population.
- Speech discrimination testing must be conducted in order to provide more information with regards to cochlea and retrocochlea pathologies. Speech discrimination in noise is also important as a tool of measurement for CAPD.

4.3 Implications of the study:

- Findings from the current study are highly significant as they highlight the fact that in-depth deficits along the auditory system may in fact occur following a CHI; hence audiological assessments should form part of the investigations that patients undergo following CHI
- Furthermore current findings highlight the need for a more extensive examination to be conducted on CHI patients and their auditory deficits with regards to more advanced hearing tests which should include, middle latency response testing, late latency response testing, P300 testing and tests for CAPD involving dichotic listening tests; as basic audiological measures may not be sensitive enough on their own as indicated in the current study.
- One of the reasons for conducting the current study was to provide information about the integrity of the auditory system following a CHI, so that abnormalities along the auditory

pathway can be easily identifiable; with the aim of consequently providing awareness of the importance of advanced auditory testing within the closed head injured population. The results of the current study can thus be used as a motivation to implement advanced audiological protocols among the closed head injured population; thus contributing to policy formulation for this population.

- It is important that all professionals involved with closed head injuries are aware of the possible auditory complications associated with a CHI, and must therefore look at hearing testing as one of the areas which is to be assessed in-depth, whenever dealing with a CHI patient. Thus current findings have implications for training of professionals and caregivers involved with CHI populations.

4.4 Recommendations for further research:

- A replication of the current study with larger sample size that includes (i) a range of diverse ethnic participants, (ii) more female participants; and (iii) participants from geographical areas other than Gauteng Province.
- It is recommended that participants are recruited from public health rehabilitation facilities as well as from the private sector, so that a large array of participants can be assessed which will allow the results to be more reflective of the South African CHI population as a whole; and increase generalizability of findings.
- It is recommended that more advanced hearing tests be conducted as these will give more in-depth information about the hearing system including the middle latency response tests, late latency response tests, P300 tests and CAPD tests which include behavioural test such as compressed speech test and monaural low redundancy speech tests, dichotic

listening tests which include dichotic digits speech test, temporal patterning tests and rapid alternating speech perception tests.

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Appendix A

Case History Form

All information is treated confidentially.

Demographic Information:

Date of Assessment: _____

Participant number: _____

Gender: _____

Age: _____

Date of Birth: _____

Home Language: _____ Other Languages Spoken: _____

Medical History:

1. Mark which illnesses you have suffered from – give age where possible

Asthma: _____ Bronchitis: _____
Chicken Pox: _____ Chorea (St. Vitus' Dance) _____
Convulsions: _____ Diabetes: _____
Diphtheria: _____ Discharge from ear(s): _____
Earache: _____ Encephalitis: _____
Epilepsy: _____ Gastro-enteritis: _____
German Measles (Rubella): _____ High Temperature: _____
Influenza: _____ Malaria: _____
Mastoiditis: _____ Measles: _____
Menieres Disease: _____ Meningitis: _____
Mumps: _____ Otitis Media: _____
Otosclerosis: _____ Pneumonia: _____
Poliomyelitis: _____ Rheumatic fever: _____
Scarlet Fever: _____ Tonsilitis/Adenoiditis: _____
Whooping Cough: _____ Heart Disease: _____
Blood pressure: _____ Circulation/Thrombosis of veins: _____
Tuberculosis: _____ Liver conditions/jaundice/hepatitis: _____
Thyroid conditions: _____ Gastric/duodenal ulcer/hiatus hernia: _____
Diarrhoea: _____ Kidney/Bladder disease: _____
Porphria (incl family): _____ Depression: _____

Back/neck problems: _____
Excessive bleeding after extractions injury or operations: _____
Any recent illness eg: cough/cold: _____
Any Other: _____

2. Were drugs taken? (If known, state name of drug?)
   a) For any of the above conditions? _____
   b) For any other condition (incl.: chemotherapy/radiation)? _____
   _____

3. Have you undergone surgery? (Please give dates and details)
   _____
   _____
   _____
   _____
   _____

4. Have you had any notable injuries, excluding the head injury?
   _____
   _____
   _____
   _____
   _____

5. When did the head injury occur?
   _____
   _____

6. Please describe the event that occurred, which resulted in a head injury?
   _____
   _____
   _____

7. What type of head injury was sustained?
   _____
   _____

8. Was there loss of consciousness at any time during or after the head injury occurred?
   _____
   _____

9. What was the Glasgow Coma Scale (GCS) score on admission into the hospital?
   _____

10. Did illness/surgery/injury have any noticeable effect on speech or hearing? (Give details)

For researcher Use:

Describe the radiological findings reported from the record review:

Communication Difficulties in General:

1. Any difficulties prior to the head injury (e.g. hearing/speech/cognitive difficulties)? Please be specific.
2. Difficulties acquired due to the head injury (e.g. speech/hearing/cognitive difficulties)? Please be specific.
3. When were the difficulties first noticed?
4. By whom were the difficulties noticed?

5. Is there a family history of any speech/hearing or cognitive deficits? If yes, please describe.

_____
_____
_____
_____

6. Does the difficulty interfere with (Mark: Yes, No, Sometimes):

Everyday home routine: _____

Efficiency at work: _____

Social Activities: _____

Personal Adjustment: _____

Hearing Status:

1. Any previous hearing assessments? If so, please provide information as to when the assessment occurred, state the reason for the assessment, and the results?

_____
_____
_____
_____

2. Have you been exposed to loud noise either socially or work related, for long periods of time?

_____
_____

3. Have you ever experienced any ringing in the ears, blocked ears or dizziness?

_____
_____
_____

4. Are you currently experiencing any hearing problems?

_____
_____
_____

5. State if you have ever experienced hearing difficulties in the past (may be related to the accident)?

6. State any further information which you feel can be related to a communication/hearing difficulty?

Appendix B

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG
Division of the Deputy Registrar (Research)

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)
R14/49 Miss Natalie Plaks

CLEARANCE CERTIFICATE	**M10362**
PROJECT	Hearing Loss in the Closed Head Injured Population, Two to Five Years Post Closed Head Injury
INVESTIGATORS	Miss Natalie Plaks.
DEPARTMENT	Speech Pathology & Audiology
DATE CONSIDERED	26/03/2010
DECISION OF THE COMMITTEE*	Approved unconditionally

Unless otherwise specified this ethical clearance is valid for 5 years and may be renewed upon application.

DATE 25/05/2010 **CHAIRPERSON** .....
(Professor PE Cleaton-Jones)

*Guidelines for written 'informed consent' attached where applicable
cc: Supervisor : Dr K Levin

DECLARATION OF INVESTIGATOR(S)

To be completed in duplicate and **ONE COPY** returned to the Secretary at Room 10004, 10th Floor, Senate House, University.
I/We fully understand the conditions under which I am/we are authorized to carry out the abovementioned research and I/we guarantee to ensure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I/we undertake to resubmit the protocol to the Committee. **I agree to a completion of a yearly progress report.**

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES...

Appendix C

HASS GROUP

Ear Institute, 1240 Webb Str. Queenswood Pretoria. Tel: (012) 333-3131 Fax: (012) 333-2298

H.A.S.S. Industrial (Pty) Ltd

Certificate of Calibration
No. H AA040837/10

Calibrated for:	**University of the Witwatersrand** Speech & Hearing Department Social Sciences Building Main Campus Braamfontein 2050
Calibration of:	1761
Manufacturer:	GSI
Serial Number:	**AA040837**
Calibration procedure:	Complete diagnostic Calibration: Audiometer (GSI 61), Earphones (TDH 50: Right s/n C013219; Left s/n C013218, Bone Vibrator (B71), Free Field (Standard 90 dB sound Field).
Traceability:	The calibration was performed using instruments traceable to national standards.
Date of Calibration:	**2010-08-30** **Cal. Due Date:** **2011-08-30**
Results:	The instrument complies with the requirements for use of a Type 1 Audiometer. (Air , Bone & Free Field).
Remarks:	None
Calibrated by:	Retief Roos _____ Signature

NOTE: The values in this certificate are correct at the time of calibration. Subsequently the accuracy will depend on such factors as the care exercised in the handling and use of the instrument and the frequency of use. Re-calibration should be performed annually to ensure that the instrument's accuracy remains within the desired limits.

Appendix D

Interacoustics®

Calibration Certificate
For
Univercity of the Witwatersrand

Date of Calibration: **2010/09/07**

Detailed Information of Equipment Calibrated

ITEM		MAKE	MODEL	SERIAL NO.
Audiometer		*Interacoustics*	*AC40*	*115443*
	Earphone Right	*Telephonics*	*TDH 39*	*C149657*
	Earphone Left	*Telephonics*	*TDH 39*	*C149198*
	Bone Conductor	*Radio Ear*	*B 71*	------
Audiometer		*Interacoustics*	*AC40*	*746412*
	Earphone Right	*Telephonics*	*TDH 39*	*C438423*
	Earphone Left	*Telephonics*	*TDH 39*	*C438438*
	Bone Conductor	*Radio Ear*	*B 71*	------
Tympanometer		*Interacoustics*	*AT235*	*740433*

List of Compliances

Item	Specification in Compliance to	Compliance Yes/No
Audiometer	*Item is certified as being in calibration in accordance with SANS 10154 part 1 and part 2: 2004 as well as IEC 60645*	**YES**
Middle ear analyzer	*Item is certified as being in calibration in accordance with EN61027 for Impedance*	**YES**

MEASURING EQUIPMENT

Sound Level Meter:	*Rion NA-28*	*Serial No: 10351705*
Artificial Ear:	*B & K, Type 4153*	*Serial No: 1365968*
Microphone:	*GRAS*	*Serial No: 16063*
Calibrator:	*B & K, Type 4230*	*Serial No: 298552*
Frequency Counter:	*Extech 350*	*Serial No: 07051406*
Artificial Mastoid:	*B & K 4930*	*Serial No: 391079*
Manometer:	*MHC1*	

Calibration Officer: KR Drews

Signature of Calibration Officer: KR Drews

Trained and Accredited by Interacoustics Denmark, 29 August 2008

Tel: 011 675 6104
Fax: 011 675 6107

Appendix E

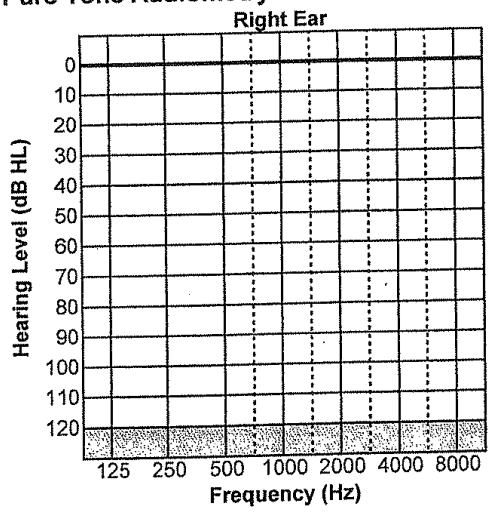
University of the Witwatersrand Speech and Hearing Clinic

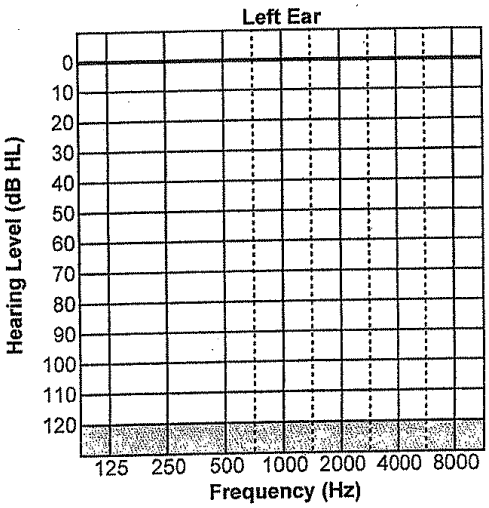
AUDIOLOGY ASSESSMENT

Name: _____ DoB: _____ Age: _____

Audiometer: _____ Audiologist: _____ Test date: _____

Pure Tone Audiometry





Masking levels

	Right Ear	Left Ear
AC		
BC		

Add to symbol if no response	masked	un-masked	Symbols	un-masked	masked	Add to symbol if no response
↙	Δ	O	AC	X	□	↘
	[	<	BC	>	]	
		S	SF	S		

Speech Audiometry

EAR	SRT dB	MCL dB	TD dB	DR dB	MASKING TYPE	MASKING LEVEL	MASKING EAR
RIGHT							
LEFT							
FF							

EAR	Mat.	SL dB	HL dB	%	MASKING TYPE	MASKING LEVEL	MASKING EAR
RIGHT							
LEFT							
SOUND FIELD							

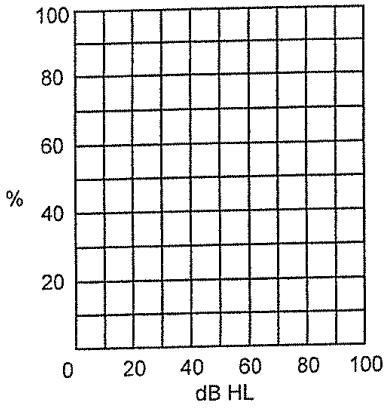
Reliability:

Good	
Fair	
Poor	

PTA (dB HL)

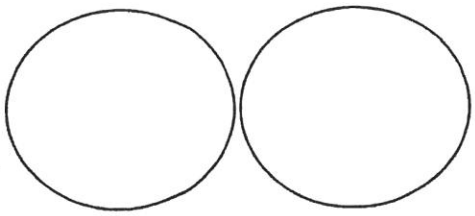
RIGHT	LEFT

Performance - Intensity function



Otoscopy

RIGHT



LEFT

Tympanometry

Ear	Type	ECV	MEP peak	Static compliance	Description
Right					
Left					

Acoustic Reflexes

RIGHT				Probe ear	LEFT			
CONTRA		IPSI		Stimulus ear	IPSI		CONTRA	
ARD % in 5s	ART dBHL	Metz dBSL	ART dBHL	Frequency Hz	ART dBHL	Metz dBSL	ART dBHL	ARD % in 5s
				500				
				1000				
				2000				
				4000				
				BBN				

Test notes: _____

_____

Additional Tests

OAEs: _____

ABR: _____

Other: _____

_____

Summary of Results: _____

_____

_____

_____

_____

_____

_____

_____

_____

Recommendations: _____

_____

_____

Audiologist: _____

Appendix F

WORD LISTS FOR C. I. D. AUDITORY TEST W.1.

LIST A.

1.	greyhound	10.	~~duckpond~~	19.	Baseball	28.	oatmeal.
2.	schoolboy	11.	~~sidewalk~~	20.	Stairway	29.	toothbrush
3.	inkwell	12.	hotdog	21.	cowboy	30	farewell
4.	whitewash	13.	padlock	22.	iceberg	31.	grandson
5.	pancake	14.	mushroom	23.	~~northwest~~	32.	drawbridge
6.	mousetrap	15.	hardware	24.	~~railroad~~	33.	doormat
7.	eardrum	16.	workshop	25.	playground	34.	hothouse
8.	headlight	17.	horseshoe	26.	~~airplane~~	35.	daybreak
9.	birthday	18.	armchair	27.	woodwork	36	sunset

LIST B.

1.	playground	10.	~~railroad~~	19	Toothbrush	28.	eardrum
2.	grandson	11.	baseball	20.	mushroom	29.	greyhound
3.	daybreak	12.	padlock	21.	farewell	30.	birthday
4.	doormat	13.	hardware	22.	horseshoe	31.	hothouse
5.	woodwork	14.	whitewash	23.	pancake	32.	iceberg
6.	armchair	15.	hotdog	24.	inkwell	33.	schoolboy
7.	stairway	16.	sunset	25.	mousetrap	34.	~~duckpond~~
8.	cowboy	17.	headlight	26.	~~airplane~~	35.	workshop
9.	oatmeal	18.	drawbridge	27.	~~sidewalk~~	36.	~~northwest~~

LIST C.

1.	birthday	10.	woodwork	19.	farewell	28.	sunset
2.	hothouse	11.	stairway	20.	mousetrap	29.	cowboy
3.	toothbrush	12.	daybreak	21.	armchair	30.	~~duckpond~~
4.	horseshoe	13.	~~sidewalk~~	22.	drawbridge	31.	playground
5.	~~airplane~~	14.	~~railroad~~	23.	mushroom	32.	inkwell
6.	northwest	15.	oatmeal	24.	baseball	33.	eardrum
7.	whitewash	16.	headlight	25.	grandson	34.	workshop
8.	hotdog	17.	pancake	26.	padlock	35.	schoolboy
9.	hardware	18.	doormat	27.	greyhound	36.	iceberg

LIST D.

1.	hothouse	10.	~~duckpond~~	19.	playground	28.	greyhound
2.	padlock	11.	baseball	20.	oatmeal	29.	mousetrap
3.	eardrum	12.	~~railroad~~	21.	~~northwest~~	30.	schoolboy
4.	~~sidewalk~~	13.	hardware	22.	woodwork	31.	whitewash
5.	cowboy	14.	toothbrush	23.	stairway	32.	inkwell
6.	mushroom	15.	~~airplane~~	24.	hotdog	33.	doormat
7.	farewell	16.	iceberg	25.	headlight	34.	daybreak
8.	horseshoe	17.	armchair	26.	pancake	35.	drawbridge
9.	workshop	18.	grandson	27.	birthday	36.	sunset

Appendix G

HASS GROUP

The Ear Institute, 1240 Webb Str. Queenswood Pretoria. Tel: (012) 333-3133 Fax: (012) 333-1124

H.A.S.S. Industrial (Pty) Ltd

Certificate of Calibration
No. D 20030112/10

Calibrated for:	**University of Witwatersrand Social Services Building Main Campus Braamfontein 2050**
Calibration of:	**GSI Audera platform**
Manufacturer:	GSI
Serial Number:	**20030112**
Calibration procedure:	Complete diagnostic calibration: ASSR instrument (GSI Audera), Earphones (Tip 50 Insert Phones).
Traceability:	The calibration was performed using instruments traceable to national standards.
Date of Calibration:	**2010-04-30** **Cal. Due Date:** **2011-04-30**
Results:	The instrument complies with the requirements for use (Insert phones).
Remarks:	**ASSR, AEP and Cortical AEP options**
Calibrated by:	Bennie Henning Signature

NOTE: The values in this certificate are correct at the time of calibration. Subsequently the accuracy will depend on such factors as the care exercised in the handling and use of the instrument and the frequency of use. Re-calibration should be performed annually to ensure that the instrument's accuracy remains within the desired limits.

Oranje Drukkery 2005 (071 675 4729) 72674

Appendix H

Participant Information Sheet

Hello,

My name is Natalie Plaks and I am a Masters Audiology student at WITS University. As part of my studies I am doing a research project entitled "*The prevalence of hearing loss in closed head injured individuals, two to five years post head injury"*. This study investigates whether or not a hearing loss is sustained after a closed head injury. If so, it will imply that a hearing test should be conducted on every individual with a closed head injury, upon their arrival to a rehabilitation facility, as well as implications for follow up hearing tests, subsequent to discharge from the rehabilitation facility. Hearing loss affects all aspects of life including emotional well being, social interaction, cognitive abilities and perceived well being and is therefore a very important aspect of rehabilitation.

If you choose to participate in this study, you will be asked to visit the University of the Witwatersrand's speech and hearing department for a full audiological assessment. I will ask you to fill out a detailed case history form indicating your head injury diagnosis, medication, time in rehabilitation etc. The assessment will take roughly 2 and a half hours, and you will undergo a complete audiological evaluation. The audiologist will inform you about all the different tests and their importance as you go along. The tests are non invasive, and will be conducted in a very relaxed environment, no risks are involved in this study. The aim of the tests is to evaluate each individual element of your hearing mechanism and to ensure that every component is healthy and working appropriately. All information obtained will remain completely confidential, where codes will be used instead of your actual name.

These assessments will be conducted free of charge, and you will gain insight into the functioning of your hearing mechanism, and whether or not there is a hearing difficulty. If a hearing difficulty is detected, you will be referred to an audiologist, who will further assist you.

Your participation in this study is entirely voluntary. You are free to decide whether you want to take part or not. You are free to withdraw from the study at any time without any negative consequences.

The information that is obtained will remain completely confidential, and will be grouped with information from other participants, such that it can never be traced to you. Your name will not be documented in the report, as I will use codes and numbers instead of names, in order to conceal your identity. The information will be used for the purposes of this study.
Your participation is greatly appreciated.

If you have any queries, or you would like any further information regarding this study please feel free to contact me on (011) 782-6825/ 071 319 1956, or if you prefer to email: nplaks@gmail.com. Thank you for taking time to consider participation in this study.

Sincerely

_____

Natalie Plaks

Appendix I

Consent Form

Thank you for agreeing to participate in this study.

I hereby confirm that I have been informed about the nature purpose and procedures of the study. I have also read and understand the participant information sheet. I may at any stage withdraw from the study, without negative consequences. I have been made aware that my name will not be used in the research report. The information obtained will be treated as confidential and will not in any way be identified with me.

I declare that I am prepared to participate in this study.

Name of participant: _____

Signature: _____

Date: _____

I, Natalie Plaks, hereby confirm that the above participant has been fully informed about the nature, conduct and risks of this study.

Signature: _____

Date: _____

Appendix J

Information Letter for Rehabilitation sites and Neuropsychologist:

Hello,

My name is Natalie Plaks; I am a Masters Audiology student from the department of Speech Pathology and Audiology at the University of the Witwatersrand. I will be conducting research for my masters thesis for partial fulfillment of my degree for Masters in Audiology. I will be conducting research in the area of closed head injuries and associated hearing loss. The aims of this proposed research is to determine whether or not a hearing loss is present with a closed head injury, if so, appropriate management protocols, such as a full audiological test battery, must be put in place. In order for my study to continue, I would like to review participant records. Information regarding the institution/person involved will remain confidential. Participant identifying information will not be published, and participant details will remain anonymous. Ethical clearance will be obtained from the University of Witwatersrand Human research Ethics committee, prior to commencement of the study.

Your participation in this study is greatly appreciated. Should you require the results of this study please indicate so and these will be provided in due time.

Should you have any queries regarding any of the above please do not hesitate to contact me.

Natalie Plaks

(Masters Audiology Student)

071 319 1956

Appendix K: Type of closed head injury associated with ABR recordings: Kruskal Wallis Test

			Count	Mean	SD	*p*-value
R AWL I tracing 1	**Type of closed head injury**	**Intracranial hematoma**	5	1.59	.15	0.094
		Concussion	21	1.53	.08	
		Diffuse axonal injury	2	1.50	.04	
		Brain contusion	2	1.50	.04	
R AWL III tracing 1	**Type of closed head injury**	**Intracranial hematoma**	5	3.72	.14	0.429
		Concussion	21	3.72	.07	
		Diffuse axonal injury	2	3.70	.24	
		Brain contusion	2	3.64	.05	
		Brain contusion	2	3.72	.12	
R AWL V tracing 1	**Type of closed head injury**	**Intracranial hematoma**	5	5.23	.34	0.210
		Concussion	21	5.42	.29	
		Diffuse axonal injury	2	5.07	.57	
		Brain contusion	2	5.60	.00	
R IWL I-III tracing 1	**Type of closed head injury**	**Intracranial hematoma**	5	2.19	.07	0.478
		Concussion	21	2.19	.05	
		Diffuse axonal injury	2	2.10	.04	
		Brain contusion	2	2.13	.00	
		Brain contusion	2	2.20	.10	
R IWL III-V tracing 1	**Type of closed head injury**	**Intracranial hematoma**	5	1.72	.21	0.471
		Concussion	21	1.79	.12	
		Diffuse axonal injury	2	1.67	.19	
		Brain contusion	2	1.87	.09	
		Brain contusion	2	1.80	.00	
R IWL I-V tracing 1	**Type of closed head injury**	**Intracranial hematoma**	5	3.81	.20	0.257
		Concussion	21	3.94	.12	
		Diffuse axonal injury	2	3.77	.23	
		Brain contusion	2	3.88	.07	

		Brain contusion	2	4.04	.05	
L AWL I tracing 1	**Type of closed head injury**	**Intracranial hematoma**	5	1.59	.03	0.978
		Concussion	21	1.58	.07	
		Diffuse axonal injury	2	1.60	.10	
		Brain contusion	2	1.60	.10	
		Brain contusion	2	1.63	.14	
L AWL III tracing 1	**Type of closed head injury**	**Intracranial hematoma**	5	3.78	.08	0.804
		Concussion	21	3.75	.13	
		Diffuse axonal injury	2	3.74	.19	
		Brain contusion	2	3.67	.19	
		Brain contusion	2	3.68	.21	
L AWL V tracing 1	**Type of closed head injury**	**Intracranial hematoma**	5	5.54	.14	0.840
		Concussion	21	5.42	.260.570	
		Diffuse axonal injury	2	5.50	.14	
		Brain contusion	2	5.53	.00	
		Diffuse axonal injury	2	5.48	.21	
		Brain contusion	2	5.60	.00	
L IWL I-III tracing 1	**Type of closed head injury**	**Intracranial hematoma**	5	2.17	.06	0.266
		Concussion	21	2.16	.06	
		Diffuse axonal injury	2	2.09	.02	
		Brain contusion	2	2.17	.05	
L IWL III-V tracing 1	**Type of closed head injury**	**Intracranial hematoma**	5	1.76	.15	0.640
		Concussion	21	1.80	.12	
		Diffuse axonal injury	2	1.87	.09	
		Brain contusion	2	1.87	.09	
		Brain contusion	2	1.90	.04	
L IWL I-V tracing 1	**Type of closed head injury**	**Intracranial hematoma**	5	3.95	.07	0.430
		Concussion	21	3.99	.23	
		Diffuse axonal injury	2	3.90	.04	
		Brain contusion	2	4.04	.05	
L IWL I-V tracing	**Type of closed**	**Intracranial**	5	3.91	.08	0.759

2	**head injury**	**hematoma**				
		Concussion	21	3.74	.62	
		Diffuse axonal injury	2	3.90	.04	
		Brain contusion	2	3.99	.02	
Interaural wave V tracing 1	**Type of closed head injury**	**Intracranial hematoma**	5	.34	.37	0.661
		Concussion	21	.19	.20	
		Diffuse axonal injury	2	.40	.47	
		Brain contusion	2	.07	.00	
		Concussion	21	.18	.20	
		Diffuse axonal injury	2	.27	.37	
		Brain contusion	2	.10	.14	

Note: R = right; L = left; AWL = absolute wave latency; IWL = interwave latency; SD = standard deviation

Appendix L: Glasgow Coma Scale scores relating to ABR recordings: Kruskal Wallis test

			Count	Mean	SD	*p*-value
R AWL I tracing 1	**GCS**	**Severe**	9	1.54	.11	0.521
		Moderate	6	1.55	.14	
		Mild	15	1.53	.07	
R AWL III tracing 1	**GCS**	**Severe**	9	3.67	.11	0.206
		Moderate	6	3.77	.09	
		Mild	15	3.71	.08	
R AWL V tracing 1	**GCS**	**Severe**	9	5.33	.39	0.105
		Moderate	6	5.58	.19	
		Mild	15	5.33	.30	
R IWL I-III tracing 1	**GCS**	**Severe**	9	2.17	.06	0.034
		Moderate	6	2.14	.04	
		Mild	15	2.20	.05	
		Mild	15	2.20	.06	
R IWL III-V tracing 1	**GCS**	**Severe**	9	1.77	.19	0.475
		Moderate	6	1.83	.08	
		Mild	15	1.76	.12	
R IWL I-V tracing 1	**GCS**	**Severe**	9	3.82	.17	0.047
		Moderate	6	4.00	.09	
		Mild	15	3.92	.13	
		Mild	15	4.01	.25	
L AWL I tracing 1	**GCS**	**Severe**	9	1.59	.05	0.612
		Moderate	6	1.61	.05	
		Mild	15	1.58	.08	
		Mild	15	1.58	.06	
L AWL III tracing 1	**GCS**	**Severe**	9	3.74	.12	0.826
		Moderate	6	3.73	.13	
		Mild	15	3.76	.13	
L AWL V tracing 1	**GCS**	**Severe**	9	5.57	.09	0.067
		Moderate	6	5.53	.19	
		Mild	15	5.35	.26	
		Mild	15	5.32	.27	
L IWL I-III tracing 1	**GCS**	**Severe**	9	2.14	.06	0.409
		Moderate	6	2.14	.08	
		Mild	15	2.17	.06	
L IWL III-V tracing 1	**GCS**	**Severe**	9	1.85	.08	0.264
		Moderate	6	1.82	.15	
		Mild	15	1.77	.12	
		Mild	15	1.77	.15	

L IWL I-V tracing 1	**GCS**	**Severe**	9	3.98	.08	0.775
		Moderate	6	3.94	.09	
		Mild	15	4.01	.27	
L IWL I-V tracing 2	**GCS**	**Severe**	9	3.70	.67	0.173
		Moderate	6	3.99	.05	
		Mild	15	3.78	.53	
Interaural wave V tracing 1	**GCS**	**Severe**	9	.29	.34	0.780
		Moderate	6	.29	.31	
		Mild	15	.15	.13	
		Mild	15	.13	.14	

Key: R = right; L = left; AWL = absolute wave latency; IWL = interwave latency; SD = standard deviation; red indicates abnormalities

Appendix M: Associations between Site of Lesion and ABR recordings

			Count	Mean	SD
R AWL I tracing 1	**Site of Lesion**	**Occipital and temporal lobes**	2	1.58	.07
		Frontal and parietal lobes	9	1.51	.10
		Temporal lobe	5	1.52	.11
		Temporal and parietal lobes	4	1.58	.07
		Right temporal lobe	1	1.60	.
		Frontal lobe	4	1.53	.00
		Parietal and occipital lobes	2	1.63	.14
		Right parietal lobe	1	1.53	.
		Frontal and temporal lobe	1	1.33	.
		Left parietal and temporal lobes	1	1.60	.
		Parietal and occipital lobes	2	1.64	.23
		Right parietal lobe	1	1.53	.
		Frontal and temporal lobe	1	1.53	.
		Left parietal and temporal lobes	1	1.53	.
R AWL III tracing 1	**Site of Lesion**	**Occipital and temporal lobes**	2	3.60	.10
		Frontal and parietal lobes	9	3.65	.10
		Temporal lobe	5	3.71	.03
		Temporal and parietal lobes	4	3.80	.09
		Right temporal lobe	1	3.73	.
		Frontal lobe	4	3.80	.06
		Parietal and occipital lobes	2	3.73	.00
		Right parietal lobe	1	3.73	.
		Frontal and temporal lobe	1	3.73	.
		Left parietal and temporal lobes	1	3.73	.
R AWL V tracing 1	**Site of Lesion**	**Occipital and temporal lobes**	2	5.57	.05
		Frontal and parietal lobes	9	5.41	.34
		Temporal lobe	5	5.43	.42

		Temporal and parietal lobes	4	5.30	.28
		Right temporal lobe	1	5.60	.
		Frontal lobe	4	5.35	.31
		Parietal and occipital lobes	2	5.17	.42
		Right parietal lobe	1	5.67	.
		Frontal and temporal lobe	1	5.27	.
		Left parietal and temporal lobes	1	4.87	.
R IWL I-III tracing 1	**Site of Lesion**	**Occipital and temporal lobes**	2	2.16	.04
		Frontal and parietal lobes	9	2.17	.05
		Temporal lobe	5	2.19	.06
		Temporal and parietal lobes	4	2.17	.09
		Right temporal lobe	1	2.13	.
		Frontal lobe	4	2.22	.07
		Parietal and occipital lobes	2	2.20	.00
		Right parietal lobe	1	2.20	.
		Frontal and temporal lobe	1	2.20	.
		Left parietal and temporal lobes	1	2.13	.
R IWL III-V tracing 1	**Site of Lesion**	**Occipital and temporal lobes**	2	1.90	.04
		Frontal and parietal lobes	9	1.80	.12
		Temporal lobe	5	1.76	.20
		Temporal and parietal lobes	4	1.72	.06
		Right temporal lobe	1	1.87	.
		Frontal lobe	4	1.75	.06
		Parietal and occipital lobes	2	1.63	.14
		Right parietal lobe	1	1.93	.
		Frontal and temporal lobe	1	1.93	.
		Left parietal and temporal lobes	1	1.53	.
R IWL I-V tracing 1	**Site of Lesion**	**Occipital and temporal lobes**	2	3.82	.02
		Frontal and parietal lobes	9	3.92	.15
		Temporal lobe	5	3.86	.24
		Temporal and parietal lobes	4	3.93	.05

		Right temporal lobe	1	3.93	.
		Frontal lobe	4	4.02	.13
		Parietal and occipital lobes	2	3.83	.14
		Right parietal lobe	1	3.93	.
		Frontal and temporal lobe	1	3.93	.
		Left parietal and temporal lobes	1	3.67	.
L AWL I tracing 1	**Site of Lesion**	**Occipital and temporal lobes**	2	1.64	.05
		Frontal and parietal lobes	9	1.56	.04
		Temporal lobe	5	1.63	.09
		Temporal and parietal lobes	4	1.58	.08
		Right temporal lobe	1	1.60	.
		Frontal lobe	4	1.60	.09
		Parietal and occipital lobes	2	1.57	.05
		Right parietal lobe	1	1.60	.
		Frontal and temporal lobe	1	1.60	.
		Left parietal and temporal lobes	1	1.53	.
L AWL III tracing 1	**Site of Lesion**	**Occipital and temporal lobes**	2	3.84	.05
		Frontal and parietal lobes	9	3.69	.14
		Temporal lobe	5	3.79	.09
		Temporal and parietal lobes	4	3.75	.15
		Right temporal lobe	1	3.60	.
		Frontal lobe	4	3.84	.11
		Parietal and occipital lobes	2	3.78	.07
		Right parietal lobe	1	3.73	.
		Frontal and temporal lobe	1	3.73	.
		Left parietal and temporal lobes	1	3.60	.
L AWL V tracing 1	**Site of Lesion**	**Occipital and temporal lobes**	2	5.50	.04
		Frontal and parietal lobes	9	5.44	.20
		Temporal lobe	5	5.57	.11
		Temporal and parietal lobes	4	5.32	.26
		Right temporal lobe	1	5.60	.
		Frontal lobe	4	5.47	.31

		Parietal and occipital lobes	2	5.34	.47
		Right parietal lobe	1	5.67	.
		Frontal and temporal lobe	1	5.63	.
		Left parietal and temporal lobes	1	5.07	.
L IWL I-III tracing 1	**Site of Lesion**	**Occipital and temporal lobes**	2	2.20	.10
		Frontal and parietal lobes	9	2.19	.06
		Temporal lobe	5	2.16	.04
		Temporal and parietal lobes	4	2.12	.10
		Right temporal lobe	1	2.20	.
		Frontal lobe	4	2.13	.05
		Parietal and occipital lobes	2	2.17	.05
		Right parietal lobe	1	2.13	.
		Frontal and temporal lobe	1	2.13	.
		Left parietal and temporal lobes	1	2.07	.
L IWL III-V tracing 1	**Site of Lesion**	**Occipital and temporal lobes**	2	1.87	.09
		Frontal and parietal lobes	9	1.81	.12
		Temporal lobe	5	1.84	.09
		Temporal and parietal lobes	4	1.72	.18
		Right temporal lobe	1	1.80	.
		Frontal lobe	4	1.81	.14
		Parietal and occipital lobes	2	1.70	.04
		Right parietal lobe	1	1.93	.
		Frontal and temporal lobe	1	1.80	.
		Left parietal and temporal lobes	1	1.87	.
L IWL I-V tracing 1	**Site of Lesion**	**Occipital and temporal lobes**	2	3.97	.14
		Frontal and parietal lobes	9	3.91	.11
		Temporal lobe	5	4.03	.06
		Temporal and parietal lobes	4	3.91	.03
		Right temporal lobe	1	4.00	.
		Frontal lobe	4	4.22	.48
		Parietal and occipital lobes	2	3.92	.07

		Right parietal lobe	1	4.07	.
		Frontal and temporal lobe	1	3.93	.
		Left parietal and temporal lobes	1	3.93	.
L IWL I-V tracing 2	**Site of Lesion**	**Occipital and temporal lobes**	2	3.92	.07
		Frontal and parietal lobes	9	3.65	.66
		Temporal lobe	5	3.98	.10
		Temporal and parietal lobes	4	3.93	.11
		Right temporal lobe	1	4.00	.
		Frontal lobe	4	4.03	.12
		Parietal and occipital lobes	2	3.90	.04
		Right parietal lobe	1	1.93	.
		Frontal and temporal lobe	1	3.80	.
		Left parietal and temporal lobes	1	3.93	.
Interaural wave V tracing 1	**Site of Lesion**	**Occipital and temporal lobes**	2	.07	.01
		Frontal and parietal lobes	9	.30	.30
		Temporal lobe	5	.28	.37
		Temporal and parietal lobes	4	.20	.23
		Right temporal lobe	1	.20	.
		Frontal lobe	4	.09	.10
		Parietal and occipital lobes	2	.17	.05
		Right parietal lobe	1	.00	.
		Frontal and temporal lobe	1	.46	.
		Left parietal and temporal lobes	1	.20	.
		Frontal lobe	4	.03	.07
		Parietal and occipital lobes	2	.21	.19
		Right parietal lobe	1	.00	.
		Frontal and temporal lobe	1	.80	.
		Left parietal and temporal lobes	1	.00	.

Key: AWL = absolute wave latency; IWL = interwave latency; I = wave I; III = wave III; V = wave V; R = right; L = left