A MULTIPLE TEST BATTERY APPROACH DURING THE ASSESSMENT OF THE AUDITORY NERVOUS SYSTEM OF PATIENTS WITH MULTIPLE SCLEROSIS

by

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ABSTRACT

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Audiologists are challenged with various neurological diseases, such as Multiple Sclerosis. This disease causes demyelination of the white matter in the central nervous system resulting in desynchronisation of neural impulses. Despite controversy in the literature many studies illustrated some degree of auditory involvement associated with this disease. The auditory brainstem response has dominated the field during the assessment of the auditory system of patients with Multiple Sclerosis. Although this objective test procedure is useful during the assessment of the auditory nerve on a brainstem level, it reveals its own set of limitations when used in isolation as a single test procedure. A multiple test battery approach has shown promise in addressing the limitations of any single test procedure. This approach aims to assess the auditory nervous system of patients with Multiple Sclerosis on different levels (sensory and neural). The aim of the current study was to determine the effectiveness of a clinically appropriate battery of test procedures during the assessment of the auditory nervous system of 25 adult subjects with Multiple Sclerosis. The subjects were divided into two groups: Group 1 consisted of fifteen (15) subjects without a history of noise exposure, whereas the ten (10) subjects in Group 2 had previously been exposed to noise.

A combined experimental-descriptive research design was selected in order to describe both the qualitative and quantitative results obtained during the study. The following test procedures were included in the test battery:

- A self-assessment questionnaire allowing subjects to report on hearing abilities, related auditory-vestibular symptoms and communicative competence during every day life;
- Puretone audiometry, distortion product otoacoustic emissions as well as the cochlear microphonic; and
- Auditory brainstem response recordings using both the rarefaction and condensation click polarities consecutively.

The results indicated that a high percentage of subjects experienced vestibular symptoms such as dizziness and vertigo by the time the study was conducted. The presence of tinnitus and hearing difficulties were uncommon among subjects. Despite this, more than half of the subjects experienced difficulty with communication in the presence of background noise. Puretone audiometry demonstrated that some of the subjects presented with mild high-frequency hearing losses. However other configurations with impaired hearing thresholds were also observed. Most of the subjects' auditory brainstem response recordings displayed abnormalities using either the rarefaction or condensation click polarity. The use of the condensation click polarity displayed more ABR abnormalities compared to the rarefaction click polarity. Several subjects displayed additional cochlear involvement while a smaller percentage of subjects presented only with neural involvement.

This study demonstrated that a single audiometric test procedure would not be effective in detecting auditory involvement in subjects with Multiple Sclerosis, and a multiple test battery approach is needed to assess the auditory nervous system at several levels. It is essential that quantitative (objective) data must be supplemented with qualitative (descriptive) data. The study led to a better understanding of this degenerative disease and the effect that it can have on the auditory nervous system of patients with Multiple Sclerosis.

Key words: *Multiple Sclerosis, battery of test procedures, multiple test battery approach, self-assessment questionnaire, puretone audiometry, distortion product otoacoustic emissions, cochlear microphonic, auditory brainstem response, rarefaction & condensation click polarities, auditory-vestibular symptoms.*

OPSOMMING

'N TOETSBATTERY BENADERING TYDENS DIE EVALUERING VAN DIE OUDITIEWE SISTEEM VAN PASIëNTE MET VEELVULDIGE SKLEROSE

deur

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Verskeie neurologiese toestande, soos Veelvuldige Sklerose, bied 'n uitdaging aan oudioloë. Hierdie toestand word veroorsaak deur demiëlinisering van die witstof in die sentrale senuwee stelsel en lei tot desinkronisasie van neurale impulse. Ten spyte van teenstrydighede in die literatuur is ouditiewe betrokkenheid gedemonstreer tydens verskeie studies. Die uitvoering van ouditiewe breinstamrespons prosedures is tot op hede hoofsaaklik tydens die evaluering van die ouditiewe sisteem van pasiente met Veelvuldige Sklerose gebruik. Alhoewel hierdie objektiewe toetsprosedure sensitief is vir abnormaliteite op 'n ouditiewe breinstam vlak, het daar ook sekere beperkinge navore gekom indien dit in isolasie as 'n enkel toetsprosedure gebruik word. 'n Toetsbattery benadering voorkom die beperkinge van 'n enkel toetsprosedure. Hierdie benadering se doel is om die ouditiewe sisteem op verkeie vlakke (sensories en neuraal) te evalueer. Tydens hierdie navorsingstudie is daar gepoog om die kliniese bydrae van 'n toetsbattery benadering vas te stel, tydens die evaluering van die ouditiewe sisteem van 25 volwasse proefpersone met Veelvuldige Sklerose. Die proefpersone was opgedeel in twee groepe: Groep 1 het bestaan uit vyftien (15) proefpersone wat nie voorheen aan hoë geraasvlakke blootgestel was nie, terwyl Groep 2 betaan het uit tien (10) proefpersone wat wel 'n geskiedenis gehad het van geraasblootstelling.

'n Eksperimenteel-beskrywende navorsingsontwerp was geselekteer om beide die kwalitatiewe en kwantitatiewe data wat verkry was gedurende die studie te beskryf. Die volgende toetsprosedures het deel uitgemaak van die toetsbattery:

- 'n Self-evalueringsvraelys wat geleentheid bied vir die beskrywing van algehele gehoorvermoëns, ouditief-vestibulêre simptome en kommunikasie vaardighede gedurende alledaagse luistersituasies;
- Suiwertoonoudiometrie, distorsie produk oto-akoestiese emmissies asook die teenwoordigheid van die kogliêremikrofoon potensiaal; en
- Ouditiewe breinstamrespons metings, waar beide die rarefraksie en kondensasie polariteite afsonderlik aangebied word.

Die resultate het aangedui dat 'n groot hoeveelheid van die proefpersone vestibulêre simptome van duiseligheid en vertigo gerapporteer het tydens die studie, terwyl die voorkoms van tinnitus en gehoorprobleme deur 'n beperkte aantal proefpersone aangedui is. Ten spyte hiervan het meer as helfte van die proefpersone probleme ondervind tydens kommunikasie in die teenwoordigheid van agtergrondsgeraas. Suiwertoonoudiometrie het aangedui dat sommige proefpersone geringe hoë frekwensie gehoorverliese gehad het, maar ander oudiogram konfigurasies was ook waargeneem. Verder het die meerderheid van die proefpersone ook ouditiewe breinstamrespons abnormaliteite vertoon wanneer die rarefraksie of kondensasie polariteit gebruik was. Meer breinstamrespons abnormaliteite was waargeneem tydens die aanbieding van die kondensasie kliek stimulus. Sommige proefpersone het gepresenteer met bykomende kogliêre skade, terwyl slegs neurale ouditiewe betrokkenheid teenwoordig was in 'n klein aantal van die proefpersone.

Die resultate het aangedui dat 'n enkel toetsprosedure nie effektief was om ouditiewe betrokkenheid by proefpersone met Veelvuldige Sklerose te identifiseer nie. 'n Toetsbattery benadering, wat beide sensoriese en neurale afwykings kan identifiseer, moet toegepas word. Dit is belangrik dat kwalitatiewe (beskrywende) data, kwantitatiewe (objektiewe) data moet aanvul. Hierdie studie het nie net gelei tot 'n beter begrip van hierdie neurologiese degeneratiewe siektetoestand nie, maar ook tot inligting aangaande die ouditiewe betrokkenheid wat kan voorkom.

Sleutelterme: *Veelvuldige Sklerose, toetsbattery, 'n toetsbattery benadering, self-evalueringsvraelys, suiwertoonoudiometrie, distorsie produk oto-akoestiese emmissies, kogliêremikrofoon potensiaal, ouditiewe breinstamrespons. rarefraksie & kondensasie kliek stimulus, ouditief-vestibulêre simptome.*

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ABBREVIATIONS

Abbreviations used in the text are as follows:

ABBREVIATION	TERM
A	Alternating click polarity
A_1	Left Ear Electrode
A_2	Right Ear Electrode
ABR	Auditory Brainstem Response
ABRs	Auditory Brainstem Responses
AL	Absolute Latency
ALs	Absolute Latencies
ANSI	American National Standards Institute
AP	Action Potential
AR	Acoustic Reflex
C	Condensation
CANS	Central Auditory Nervous System
CAP	Central Auditory Processing
CM	Cochlear Microphonic
CMs	Cochlear Microphonics
cm^3	Cubic centimeter
CNS	Central Nervous System
COM-C	Communication Complaint List
CT	Computed Tomography
C_z	Vertex Electrode
daPa	decaPascal
dB	Decibel
DP	Distortion Product
DPgram	Distortion Product "Audiogram"

ABBREVIATIONS (continued)

DPOAE	Distortion Product Otoacoustic Emission
DPOAEs	Distortion Product Otoacoustic Emissions
EcochG	Electrocochleography
EEG	Electroencephalography
EMG	Electromyography
ENG	Electronystagmography
f_1	Lower Frequency
f_2	Higher Frequency
F_z	Forehead Electrode
GSI	Grason Stadler Instrument
Hz	Hertz
ILD	Interaural Latency Difference
IPL	Interpeak Latency
IPLs	Interpeak latencies
kHz	Kilo Hertz
L_1	Intensity Level of f_1
L_2	Intensity Level of f_2
LVR	Late Vertex Response
MLD	Masking Level Difference
MLR	Middle Latency Response
MRI	Magnetic Resonance Imaging
MS	Multiple Sclerosis
msec	millisecond
µV	microvolt
NF	Noise Floor
nHL	Normal Hearing Level
NR	No Response

ABBREVIATIONS (continued)

OAE	Otoacoustic Emission
OAEs	Otoacoustic Emissions
PB	Phonemically Balanced
PP	Primary Progressive
R	Rarefaction
RR	Relapsing-remitting
RSEE	Rating Scale for Each Ear
SABS	South African Bureau of Standards
SD	Standard Deviation
SPL	Sound Pressure Level
SRT	Speech Reception Thresholds

CHAPTER 1

ORIENTATION AND RATIONALE OF THE STUDY

How can you look so good and be ill?
I really cannot understand it still
How is it one day you feel so fine,
And another you seem like you're losing your mind?

This MS thing is a mystery it's true,
Did you say you feel dizzy and wobbly and blue?
Do you always get tired from a walk around town?
I told you I'm up and then I am down
Terri (unknown)

1.1 INTRODUCTION

Multiple Sclerosis (MS) remains a mystery both to patients suffering from it, and the medical profession and audiologists concerned with the assessment thereof. This is one of the most common types of demyelinating diseases in adult neurological impairment, excluding the geriatric population (Hall, 1992). Multiple Sclerosis is a chronic inflammatory disease of unknown origin, unpredictable course and prognosis, as well as high variability regarding the pathology and the symptom pattern (see Appendix A for a comprehensive description of the disease). Symptoms are also likely to be multiple, whether they are temporary or persistent, and are determined by the pathways that are demyelinated. Multiple areas in the central nervous system (CNS), especially the white matter surrounding the ventricular system of the cerebral hemispheres, the brainstem, cerebellum, optic nerves and spinal cord, can be affected by demyelination (Lechtenberg, 1995). Since the brainstem is the site of frequent demyelination according to McAlphine et al. (1972) and Lechtenberg (1995), researchers have assessed the auditory pathways in this small compact area to determine the extent of auditory and vestibular involvement since 1977 (Elidan et al., 1982; Hall, 1992). Some auditory and vestibular involvement can be expected in patients suffering from Multiple Sclerosis.

This chapter will provide an overview on the shortcomings of using a single test procedure, or only the basic audiometric test battery, when assessing the auditory nervous system of patients with Multiple Sclerosis. The importance of implementing a multiple test battery approach for assessing the sensory and neural auditory nervous system will be discussed. The need to include the assessment of cochlear function, as well as the self-assessment of hearing ability, related auditory-vestibular symptoms and communicative competence during every day life, will be outlined. This delineates the purpose of the study: to determine whether a clinically appropriate multiple test battery approach will be able to determine the auditory involvement present in patients with Multiple Sclerosis.

1.2 PROBLEM STATEMENT AND RATIONALE OF THE STUDY

Certainly not all, but a considerable number of patients with Multiple Sclerosis, have some type of auditory deficit (Musiek et al., 1994). The incidence of auditory abnormalities and hearing difficulties in the MS population is underestimated (Musiek et al., 1994). Furthermore related symptoms such as auditory-vestibular involvement are often overlooked. These symptoms include balance disorders, vertigo, dizziness and tinnitus, and are associated with MS in more than 80 % of sufferers (Daugherty et al., 1983). The MS population poses a challenge to researchers, since the disease can manifest in many different areas of the auditory nervous system. In the auditory pathway, the disease generally has its primary site in the brainstem (proximal half) and auditory abnormalities are mostly described as retrocochlear in nature (McAlphine et al., 1972). Demyelinating lesions have also been reported at the root of the cranial VIIIth nerve (distal half) in 10 % of the cases (Jacobson et al., 1987).

Literature abounds with controversy on whether or not MS is associated with some particular characteristic form of auditory involvement (Stach et al., 1990). As such, the opinions on the number and quality of hearing loss in MS vary considerably (Grénman, 1985). This may partly be due to the diverse nature of the disease, but can also be attributed to the audiometric test procedures selected to assess the auditory nervous

system. Within the MS population an audiologist can encounter an individual with normal hearing sensitivity, normal speech understanding, subjective complaints of hearing difficulty and no measurable auditory brainstem response (ABR), whereas another may present with normal ABR recordings and hearing sensitivity, but reduced speech understanding ability. The forms of auditory involvement may include subjective complaints of difficulty with hearing and/or hearing impairment of varying degrees, audiometric configurations and/or neural auditory involvement. Hearing impairment resulting from MS has been described either as unilateral or bilateral; sudden or insidious; acute or chronic; mild to severe; and high-frequency, "dome-shaped," or low-frequency in configuration (Dayal et al., 1970; Cohen & Rudge, 1984). Although reports of acute hearing loss with the onset or exacerbation of MS symptoms have been received, it remains a rare phenomenon (Hall, 1992; Özünlü et al., 1998). In these cases sudden sensory-neural hearing loss is often temporary and in some studies it was found that hearing sensitivity did return to normal. Furman et al. (1989) believe that hearing defects in MS might be missed due to their temporary nature.

Accurate large-scale statistics on the incidence of hearing loss specifically due to MS are not available. Reported incidence of hearing loss in patients with Multiple Sclerosis varies markedly, ranging from as low as 1 % to as high as 86 % (Hall, 1992). The very low percentage can perhaps be explained by the following:

- A low percentage of patients report hearing difficulties (Müller, 1949; Grénman, 1985). This finding correlated with a study performed in South Africa where only 23 % of the patients reported difficulty with hearing. The patients rated their hearing problems as insignificant when compared to other MS-related symptoms (Klugman, 2000). Hearing deficits are not typically the most debilitating symptoms experienced and patients with Multiple Sclerosis are often overwhelmed by more invalidating and disabling symptoms (Daugherty et al., 1983; Rappaport et al., 1994). Therefore, they are more likely to report major symptoms and, if not questioned, may fail to mention hearing difficulties or associated symptoms.

- The type of hearing defect is often a mild high-frequency unilateral hearing loss and could go unnoticed by the patients themselves, and is often not detected during a routine physical examination by medical practitioners or during the use of tuning forks (Furman et al., 1989; Hall, 1992).

- Subtle auditory problems, in the absence of any clinical indications of abnormality may exist but go undetected (Mustillo, 1984). Testing of auditory function may be perfunctory or omitted completely from the neurological examination. If patients with Multiple Sclerosis do undergo a hearing assessment, it often involves only the basic battery of tests and auditory deficits associated with higher auditory pathways often remain undetected.

This explains why difficulty with hearing or mild hearing losses may remain a hidden handicap. On the other hand the high percentage reported in some studies is more difficult to explain. It is possible that the battery of test procedures selected in those studies could have played a role in the higher number of abnormalities found.

Hicks (1982), reported on the shortcomings of using only the **basic audiometric test battery** when assessing patients with Multiple Sclerosis. The puretone audiogram and/or word discrimination scores lack test sensitivity regarding the neuro-otological deficits related to the demyelinating process. This finding was supported by Daugherty et al. (1983) and Grénman (1985). For instance the determination of speech reception thresholds (SRT) has been considered to be a relatively poor indicator of the central lesions caused by MS in the auditory pathways (Noffsinger et al., 1972). When the effect of age, sex and other factors not related to MS are excluded, the results of the basic test battery, like puretone thresholds and speech understanding in a quiet test environment, are very often within normal limits. In addition to this, the results of the basic audiometric test battery provided limited to no information on whether or not a patient is experiencing hearing difficulty during daily communication (Alphiner, 1982). When labels such as "slight", "mild" or "moderate" hearing loss are used, they should always be supplemented with further information describing communicative competence (Yantis, 1994). Due to the shortcomings of the basic audiometric test battery, it cannot be used in

isolation and should be used in conjunction with other audiometric test procedures, such as auditory evoked potentials.

Many researchers have shifted their attention to the use of **auditory evoked potentials** such as the ABR. ABRs have been extensively used since the 1970s to evaluate the integrity of the auditory nerve in patients with Multiple Sclerosis (Jerger et al., 1986). However the sensitivity of ABR in detecting abnormalities in MS varies, ranging from as low as 0 % to as high as 93 % (Weldon et al., 1983). The high degree of ABR variability and discrepancies between studies can be attributed to several factors, such as:

- *procedural differences*, such as whether ipsi- or contralateral recordings were performed and/or slow or fast repetition rates were presented;
- *wave interpretation*, such as the presence of Wave V, interpeak latencies (IPL) and/or Wave V/I amplitude ratios as criteria for ABR abnormality;
- *disease status* either being possible, probable or definite MS, and the *site and number of myelinated plaques* formed on the auditory pathway; and
- *statistical measurements* using either ± 2, 2,5 or 3 standard deviations (SD) from the mean (Jacobson et al., 1987).

Several studies conducting ABRs did not routinely include puretone audiometry, and normal hearing sensitivity was predicted on the assumption that subjects could hear 0 dBnHL while listening to a click stimuli. This could have resulted in low-frequency hearing losses going undetected.

Although conflicting results on the number of ABR abnormalities remains a problem, this does not justify the exclusion of ABR from the test battery. ABR is an objective tool for assessing VIIIth nerve and brainstem abnormalities in MS (Hosford-Dunn, 1985).

Only a limited number of studies have examined the cochlear function of patients with Multiple Sclerosis by using **auditory evoked responses**. According to some reports, involvement of the auditory nervous system originates in the retro-labyrinthine area or brainstem region and hearing impairment in this disease has retrocochlear features (Furman et al., 1989). This may explain why procedures such as otoacoustic emissions

(OAEs) and Electrocochleography (EcochG) were not included during the assessment of the auditory nervous system in patients with Multiple Sclerosis (Nishida et al., 1995). Furthermore OAEs have only been used in the field of diagnostic audiology since the mid 1990s (Martin et al., 1990). OAEs and EcochG were used in the 1990s in single case studies of sudden deafness, as a tool for differential diagnosis between cochlear and retrocochlear lesions. Clearly, more information regarding the cochlear function of patients with Multiple Sclerosis is needed. Therefore, an examination of the cochlear function, to determine whether or not the hearing impairment in this disease is only of retro-labyrinthine origin and causes no damage to the hair cells of the cochlea, should still be performed.

Several studies were performed without addressing the **self-assessment** of hearing abilities, associated auditory symptoms and communicative competence during every day life of patients with Multiple Sclerosis. Only a limited number of research studies assessed subjective auditory complaints and associated auditory-vestibular symptoms such as tinnitus, dizziness and vertigo. The reason for this may be that researchers concluded that difficulty with hearing was one of the less significant symptoms of the disease; or that if a hearing loss occurred, it was of a mild degree not having a negative impact on communicative competence. Furthermore studies including patients' own perception of their hearing abilities and related auditory symptoms, only used a limited number of questions to address this matter (Musiek et al., 1989; Protti-Patteron & Young, 1985). Yet, despite the lack of in-depth questions, the percentage of patients reporting difficulty with hearing was found to be higher than in other studies (Musiek et al., 1989). More than 40 % of subjects with normal hearing sensitivity presented with subjective complaints of hearing difficulties in either simple or complex listening situations. Thus subjective complaints of hearing difficulty may not always correlate with puretone thresholds. Musiek et al. (1989) indicated that the hearing complaints were related to brainstem dysfunction, which was also confirmed by the presence of ABR abnormalities.

The fact that researchers did not include self-assessment of hearing complaints as part of the battery of test procedures may be related to the fact that this type of assessment has several shortcomings. Firstly, reported hearing difficulties do not enable researchers to

ascertain a possible site of lesion and secondly some hearing difficulties may not be reported, since MS often silently affects the central auditory nervous system (CANS).

From the above discussion it is clear that discrepancies exist among the audiometric findings of different studies, contributing to the controversy on whether or not MS could be associated with auditory abnormalities or whether a characteristic form of auditory involvement is present. In spite of these controversies Jerger et al. (1986) and Musiek et al. (1989) concluded that there was a relatively high incidence of auditory abnormalities in their subjects with Multiple Sclerosis that could only be discovered through the use of appropriate test procedures.

Appropriate audiometric test procedures should assess the auditory nervous system at several levels (sensory and neural), especially when taking the pathophysiological nature of the disease into account. These procedures should be sensitive not only to lesions in the brainstem, but also include the patients' subjective perception of hearing abilities, associated auditory-vestibular symptoms and communicative competence during every day life.

The discussed limitations and existing controversies led to this study. The need to implement a clinically appropriate battery of test procedures to assess several levels of the auditory nervous system in patients with Multiple Sclerosis has been identified. For the purpose of this study it was decided to implement a self-assessment questionnaire, puretone audiometry, distortion product otoacoustic emissions (DPOAEs), cochlear microphonics (CMs) and ABRs.

The research question is whether a clinically appropriate battery of test procedures will be able to effectively describe the auditory involvement of patients with Multiple Sclerosis.

1.3 DEFINITION OF TERMINOLOGY USED IN THE STUDY

In order to prevent misinterpretation the following key concepts used in the current study were defined by the researcher as follows:

- *Auditory-vestibular symptoms:* This includes symptoms such as tinnitus, vertigo, dizziness and a feeling of being off-balance.
- *Sensory hearing loss or involvement:* Hearing impairment due to sensory, specifically cochlear involvement.
- *Neural hearing loss or involvement:* Involvement of the neural auditory nervous system ranging from distal (auditory nerve) to proximal (brainstem).
- *Basic audiometric test battery:* This includes procedures determining puretone thresholds, speech reception thresholds and discrimination scores in a quiet test environment, as well as immittance measurements.
- *Participants:* Those patients who volunteered to be part of the study, but still have to meet the selection criteria developed. Those patients included in the preliminary study are also described as participants.
- *Subjects:* Those patients who met the selection criteria developed for the study, and ultimately formed part of the sample.

1.4 CHAPTER LAYOUT

The study will be presented according to the following layout.

- **Chapter one: Orientation and rationale for the study**

The purpose of this chapter is to identify a specific research problem related to the auditory involvement of patients with Multiple Sclerosis and to provide a rationale for the current study. This chapter includes the research question and definitions of the terminology that will be used during the current study.

- **Chapter two: Signs and symptoms of auditory involvement associated with Multiple Sclerosis**

This chapter will discuss and evaluate the audiometric test procedures commonly used in studies on patients with Multiple Sclerosis. Procedures including the basic test battery, evoked responses and central auditory processing measurements will be discussed. A critical evaluation of the results will be supplied and limitations will be discussed. This will be followed by a critical discussion of studies that have implemented a multiple test battery approach. The worth of such an approach as the appropriate procedure to assess the auditory nervous system of patients with Multiple Sclerosis will be substantiated.

- **Chapter three: Research methodology**

This chapter will describe the operational framework implemented to conduct the empirical research. Reference to the main aim and sub-aim of the study, research design, procedures for subject selection, selection criteria, material and apparatus, compilation of the assessment battery, data collection and recording, and the statistical analysis of data will be supplied.

- **Chapter four: Results and discussion**

This chapter will present the results obtained during the statistical analysis. Results will be presented according to the sub-aims stipulated in Chapter three. After each presentation of results, an interpretation and discussion of its value and implications in relation to the literature will be discussed.

- **Chapter five: Conclusion, implications and recommendations**

This chapter will consist of a critical evaluation of the study. Conclusions of the findings will be provided in conjunction with the theoretical and clinical implications. Implications for the medical profession and MS population will be discussed.

Recommendations for clinical use and future research will be made, followed by the final comments.

1.5 SUMMARY OF CHAPTER 1

This chapter aimed to provide relevant background information in order to elucidate the topic of the study and to create a broad perspective on the importance of the rationale for this research study. Patients with Multiple Sclerosis may display auditory and vestibular symptoms. Controversy however exists regarding the specific nature of auditory symptoms and the incidence of hearing impairment in MS. The assessment of the auditory nervous system of patients with Multiple Sclerosis cannot be performed effectively by using a single test procedure, and due to the diverse nature of the disease a multiple test battery approach assessing several levels of the auditory nervous system should be implemented. Attention was drawn to the need for assessing the cochlear function of patients with Multiple Sclerosis and also to include their subjective perception of their hearing abilities, related auditory-vestibular symptoms and communicative competence during every day life. The purpose and variations of ABR recordings were discussed, being the most common objective test procedure used in the MS population. The implementation of a clinically appropriate multiple test battery was recommended.

CHAPTER 2

SIGNS AND SYMPTOMS OF AUDITORY INVOLVEMENT ASSOCIATED WITH MULTIPLE SCLEROSIS

2.1 INTRODUCTION

Hearing loss is considered a non-typical symptom of MS (Hall, 1992). This may partially be as a result of other more invalidating symptoms, causing hearing loss to go unnoticed. Furthermore mild unilateral hearing losses often tend to go undetected by patients with Multiple Sclerosis. Questions regarding hearing abilities, associated auditory-vestibular symptoms (such as tinnitus, vertigo and dizziness) and communicative competence during every day life, may be omitted during the routine clinical evaluation leading to these symptoms not being easily identified. In this regard Jerger et al. (1986) found that auditory dysfunctions in MS are a frequent occurrence, but these are usually sub-clinical (silent) and mild.

It has also been found that the results of the basic audiometric test battery, including puretone thresholds, speech reception threshold and speech discrimination abilities in a quiet test environment, are often within normal limits, although variability has been found (Grénman, 1985; Noffsinger et al., 1972 & Daugherty et al., 1983). Furthermore, MS lesions appear to be largely silent and not easily detected using auditory tests, such as puretone audiometry, speech discrimination, masking level differences and interaural level discrimination. The common feature of all these test procedures is that there is no requirement for precise neural synchrony. In order to detect the presence of a sound, the CANS is only required to detect an increased level of neural activity in the auditory afferent pathway during the interval over which the tone is presented, typically a period of several seconds. Whether a nerve impulse arrives a few milliseconds late in response to the tone, will probably not affect the decision about whether the tone has been detected or not (Levine et al., 1994). Antonelli et al. (1987) concluded that central lesions, as might

be present with MS, do not substantially affect the audiometric threshold level. This may also account for the low percentage of abnormal hearing sensitivity found in patients with Multiple Sclerosis.

Despite these preceding comments, reports of MS-related hearing loss have appeared in the literature since the early 1890s. Since then, the literature abounded with controversy on whether or not MS is associated with a particular form of auditory dysfunction.

The purpose of this chapter is to provide a theoretical framework for the empirical research through a critical evaluation and interpretation of relevant literature. This will be achieved by discussing possible sites of auditory involvement in MS. Furthermore previously implemented audiometric tests procedures during the assessment of the auditory nervous system of patients with Multiple Sclerosis will be evaluated in terms of their contributions and/or limitations.

Firstly, an overview of existing knowledge regarding the auditory involvement found in patients with Multiple Sclerosis will be provided. The cochlea, VIIIth nerve and brainstem will be included in the discussion. This overview of what is currently known about the auditory nervous system of patients with Multiple Sclerosis, and the problems and issues surrounding it, will provide a base of information from which the method of this study can be established and results discussed and explained.

Secondly, the published research results on audiometric issues will be presented in the following order: basic audiometric test battery, auditory evoked responses and results of central auditory processing assessment procedures. The relationship between MS and impaired hearing sensitivity will also be reviewed, since this is a controversial issue that needs to be considered during research on the auditory system of patients with Multiple Sclerosis. The existing high variability between the number of ABR abnormalities in patients with Multiple Sclerosis, and possible reasons, will be discussed. Finally the need for further assessment of cochlear function will be outlined.

The elements of a multiple test battery approach: case history information, basic audiometric test battery and site-of-lesion testing, will be supplied. Studies using a multiple test battery approach will be investigated, including diverse studies on related auditory-vestibular symptoms. The self-assessment of a patient's hearing ability and communication competence during every day life will be summarised. These theoretical foundations play an important organisational role in establishing terminology, selecting and formulating research aims, and providing a framework for the interpretation of the results of the current study.

2.2 AUDITORY INVOLVEMENT ASSOCIATED WITH MULTIPLE SCLEROSIS

Patients with Multiple Sclerosis are known to have CNS lesions and when the cortical or brainstem auditory pathways are involved, a central auditory disorder can be present (Silman & Silverman, 1991). Of all the neurological systems, the auditory system (at brainstem level) is probably the system most dependent upon precision in neural timing, and for this reason assessing this system shows great promise for identifying the physiological changes as a result of MS, both for research as well as diagnostic and therapeutic purposes (Levine et al., 1994).

The MS population is a particularly interesting group to study, as the demyelinating nature of the disease essentially results in a disruption of neural timing due to the fact that the transmission of signals is delayed or blocked completely. Therefore demyelination in the CNS may desynchronise or reduce the neural activity, either traveling toward (sensory pathway) or away (motor pathway) from the brain, ultimately decreasing or totally blocking the conduction of the affected neurons (Jacobson & Jacobson, 1990). These phenomena of desynchronisation and slowing of neural conduction can also be present in the VIIIth nerve.

Hearing is a perception that is intimately related to sensation in time. Mustillo (1984) stated that a contributing factor for patients' hearing difficulties could be a deficit in temporal processing, presumably related to delays of signal transmission within the auditory pathways. One of the characteristic features of MS is the presence of silent lesions, i.e. regions of disease involvement for which no corresponding neurological sign or symptoms can be detected. This characteristic has made it difficult to follow the course of the disease by neurological examination, since the site of lesions may fluctuate without any associated signs or symptoms.

Any portion of this system may be affected, as the distal part of the auditory nerve is covered with peripheral myelin and the central part with central myelin (Verma & Lynn, 1985). Demyelination can result in pre-neural and/or neural involvement, and therefore needs to be assessed with audiometric test procedures sensitive to lesions in these parts. Despite these recommendations, many studies have restricted their assessment to either preneural (outer ear, middle ear and cochlea) or neural (VIIIth nerve and brainstem) sites. One reason for this is the differing aims of the studies conducted; for example: Antonelli et al. (1988) aimed to compare the presence of brainstem lesions by using ABR recordings and contrasting it with MRI findings. Thus only the neural structures of patients with Multiple Sclerosis were assessed. The time frame also determined which test procedures were readily available at that stage, for example Musiek et al. (1989) implemented seven different test procedures, without including DPOAEs, possible due to its unavailability.

Until recently, the effects of MS were thought to be restricted to the CANS. However, evidence has shown segmental demyelination (Pollack et al., 1977) and abnormal refractory periods (Hopf & Eysholdt, 1978) in the peripheral nerves of patients with Multiple Sclerosis. While recording ABR and EcochG to confirm the presense of Wave I, Hopf and Maurer (1983) tested 71 patients with Multiple Sclerosis and found that 11 % exhibited prolonged Wave I latencies. They attributed peripheral involvement to segmental demyelination of the distal part of the acoustic nerve. There appears to be anatomical support for their conclusion. However, the extent of peripheral involvement caused by MS, is still poorly defined despite numerous investigations (Grénman, 1985).

Parving et al. (1981) investigated the use of EcochG and emphasised the need for methods to assess the cochlear function of patients with Multiple Sclerosis, as it is evident that the literature is lacking information in this area. The relatively recent development of OAE measurements provides a useful tool to efficiently and objectively assess the cochlear function of patients. A further advantage of applying this measurement is that it plays an important role in the differential diagnosis between cochlear and neural involvement, when used in combination with ABR.

It is apparent that auditory involvement is present in the MS population, but due to the diverse nature of the disease, a clear pattern of involvement cannot be identified. Assessment needs to be comprehensive in order to determine the presence and nature of auditory involvement in each individual patient with Multiple Sclerosis. This is an ongoing process, as the course of the disease fluctuates.

2.3 ASSESSMENT OF PATIENTS WITH MULTIPLE SCLEROSIS USING THE BASIC AUDIOMETRIC TEST BATTERY

2.3.1 Findings of puretone audiometry

Most, but not all studies, used puretone audiometry to determine the hearing sensitivity of patients with Multiple Sclerosis. Earlier studies noted that 59,1 % of a group of patients with Multiple Sclerosis demonstrated puretone losses, as compared to 27,3 % in a closely matched control group (Dayal & Swisher, 1967). High-frequency hearing losses were the most common configuration found during that study. It was concluded that there was a small and definite number in the MS group, where puretone hearing losses were secondary to the demyelinating process. Unilateral or bilateral mild, high-frequency hearing losses were reported by Musiek et al. (1989) and Rappaport et al. (1994), although a profound hearing loss was documented in research conducted by Shea and Brackmann (1987) and Marangos, (1996). Dayal et al. (1970) also concluded a descending curve to be the most often observed configuration illustrated in 67 % of cases, followed by a flat configuration

(17 %) and low-frequency hearing losses (4 %). No dome-shaped configurations were reported. The study concluded that the abovementioned descending puretone losses represented VIIIth nerve involvement and that the pathology was in the neural structures of the auditory system. On the contrary Cohen & Rudge (1984) reported that patients with definite Multiple Sclerosis presented with thresholds within normal limits, but auditory acuity at some of the low frequencies was found to be significantly worse in more than half of the patients. Simpkins (1961) also confirmed that low frequencies were specifically affected in patients with Multiple Sclerosis.

Luxon (1980) found that 58 % of patients with brainstem lesions due to MS had significant hearing losses, but no consistent audiometric pattern was identified. Weldon et al. (1983) also stated that approximately 50 % of patients with Multiple Sclerosis presented with mild puretone losses at various frequencies.

Özünlü et al. (1998) provided the following valuable predictions of puretone findings in patients with Multiple Sclerosis:

- If the demyelinating lesions encroach upon or occur at the root of the VIIIth nerve, it may result in a high-frequency hearing loss in a way similar to the effects of cochlear nerve tumors.
- If the demyelinating lesions occur in the auditory brainstem, it may result in a low-frequency hearing loss of a type similar to the effects of other forms of brainstem lesions.
- If oedema occurs in the tissue surrounding the demyelinating lesion, it may result in a sudden loss of hearing. These patients' hearing loss may show rapid improvement, probably due to the result of decreasing acute and extensive demyelination and/or resorption of oedema in the auditory pathways.

2.3.2 Findings of speech audiometry

As early as 1975 Colletti already found that speech audiometry was of minimal value during the clinical assessment of patients with Multiple Sclerosis. Dirks (1978) found that

the CANS of patients with Multiple Sclerosis was resistant to hearing loss as measured by puretone audiometry and simple speech stimuli. Supporting these findings, Keith and Jacobson (1985) stated that the findings of conventional speech audiometry have not contributed significantly toward the assessment of auditory deficits in patients with Multiple Sclerosis. The understanding of single syllable phonemically balanced (PB) words, measured in a quiet test environment, is usually normal in cases of MS (Stach et al., 1990; LeZak & Selhub, 1966; Grénman & Salmivalli, 1982; Jacobson et al., 1983). Some researchers have reported PB word score abnormality, but these percentages were low, ranging from 3 % (Grénman, 1985) to 7 % (Noffsinger et al., 1972).

The literature does differentiate between speech audiometric results measured in background noise or competition, and those measured in a quiet test environment. Some speech audiometric results were found to be abnormal in patients with Multiple Sclerosis, when measured with a competing signal. As a rule, tests performed in the presence of a competing signal are generally sensitive to VIIIth nerve or auditory brainstem disorders.

2.3.3 Findings of acoustic reflex measurements

Musiek et al. (1989) illustrated that the analysis of reflex thresholds, determining its presence or absence and the use of reflex decay measurements, are less sensitive to lesions caused by MS. However, Jerger et al. (1986) demonstrated a high percentage of abnormal acoustic reflexes (AR) in patients with Multiple Sclerosis when applying advanced reflex analysis procedures. The acoustic reflex results were examined by analysing suprathreshold amplitude and latency characteristics, in a large group of patients. Abnormality was observed in 75 % of the study population and acoustic reflexes were altered as a result of retrocochlear auditory disorders, so frequently associated with MS.

The results of puretone audiometry provides information on the degree and type of hearing loss (normal vs. abnormal, conductive, sensory-neural or mixed), but only limited information concerning communicative competence during every day life and/or the

site-of-lesion. This limitation is partly addressed by supra-threshold speech audiometry. Results of speech audiometry provide data in assessing the validity of puretone thresholds (Roeser et al., 2000). However the results of speech audiometry performed in a quiet test environment was often within normal limits for patients possibly due to the high redundancy of information found in speech signals (Sanders, 1971). When the speech signal is presented with a competing signal, diagnostic information regarding the site-of-lesion can be obtained (Roeser et al., 2000). Acoustic reflexes were useful during the assessment of patients with Multiple Sclerosis, but only when using advanced analysis procedures, which were not available during the current study.

Although puretone and speech audiometry form the foundation of the basic test battery, it is clear that it should not be used in isolation when assessing patients with Multiple Sclerosis. Due to the diverse nature of the disease, the basic battery of tests needs to be supplemented with other audiometric site-of-lesion test procedures (assessing the neural system), in order to differentiate between pre-neural and/or neural involvement.

2.4 ASSESSMENT OF PATIENTS WITH MULITPLE SCLEROSIS USING AUDITORY EVOKED RESPONSES

2.4.1 Findings of EcochG and OAEs

The use of evoked responses such as EcochG and OAEs have been applied minimally in MS studies as tools for the assessing the cochlear function. Parving et al. (1981) applied EcochG and observed intensity-dependent prolongations of the action potential (AP) latencies and decreased AP amplitudes in nine patients with Multiple Sclerosis, despite normal or near-normal puretone thresholds at 2 000Hz. The authors presented these findings as evidence of cochlear involvement. Suggested mechanisms causing this deviant findings were entirely hypothetical and included: altered synaptic transmission in the cochlear-eighth nerve region, plaques in the neuroglial part of the VIIIth nerve, and

efferent innervation of the cochlea. Lesions causing an altered activity in the efferent nerve fibres originating in the brainstem, might result in a dysfunction of the peripheral sensory structures.

Nishida et al. (1995) used OAEs and EcochG to assess the cochlear function of patients with Multiple Sclerosis displaying unilateral sudden loss of hearing. Both tests indicated normal responses, suggesting normal cochlear function. Cevette et al. (1995), Robinette and Facer (1991) as well as Yamasoba et al. (1997), reported case studies of patients with Multiple Sclerosis presenting with sudden unilateral hearing losses. Due to normal OAEs, cochlear pathology was ruled out as a possible cause of these sudden sensory-neural hearing losses, and the abnormalities were described as retrocochlear in nature. Sudden hearing losses are not a common occurrence associated with MS (being reported in approximately 1 % of patients), and cochlear pathology does not seem to be the cause.

2.4.2 Findings of brainstem auditory evoked responses

Brainstem auditory evoked responses, also known as ABRs, have become a useful clinical tool during the assessment of patients with demyelinating diseases, such as MS, because of its sensitivity to disruption of nuclei and pathways in the deep pons. This procedure is so sensitive that it could pick up a delay of just a fraction of a millisecond, if such a delay is present in the specific brainstem pathway tested (Nuwer, 1990).

The aim of performing ABRs in patients with Multiple Sclerosis is firstly to demonstrate involvement of the auditory pathways in the pons and the midbrain (VIIIth nerve lesions) and secondly to detect silent lesions. These lesions can also be identified by magnetic resonance imaging (MRI), for which corresponding functional deficits have not yet been found. ABRs are sensitive in detecting physiological changes that are not accompanied by physical signs of localising problems, or so called silent lesions (Nuwer, 1990; Lechtenberg, 1995). Detection of these silent lesions can assist in the diagnosis of MS by providing evidence of a second or third lesion in early clinical MS.

Numerous studies extensively investigated the application of ABRs in patients with Multiple Sclerosis, since the late 1970s. Earlier studies by Robinson and Rudge (1975), Shanon et al. (1979), Starr and Achor (1975), and Lynn et al. (1980) indicated that a substantial number of patients with Multiple Sclerosis demonstrated ABR abnormalities. Estimates of abnormalities ranged from 34 % (Chiappa & Norwood, 1977) to 73 % (Robinson & Rudge, 1975). The overall percentage of abnormalities is the summation of patient subgroups classified as definite, probable, or possible MS. More recently, the reported rates of ABR abnormality in MS has ranged from 0 to 93 %, with an average of 61 % across 16 studies (Jerger et al., 1986). The incidence and types of ABR abnormalities vary significantly between studies, due to the following:

- **Different classifications** (possible, probable, definite) in which patients' symptoms were categorised. Patients with *definite or confirmed* Multiple Sclerosis display symptoms of at least two separate CNS lesions, and a history of exacerbations and remission, whereas patients with *possible and probable* Multiple Sclerosis display a presence of one or more lesions, without exacerbations and remission of symptoms (Quaranta et al., 1986). Different classifications can account for the difficulty in comparing the results of various studies with one another. For example Lynn et al. (1980) found ABR abnormalities in 75 % of patients diagnosed with *definite* MS, 33 % when classified as *probable* MS, and 29 % when the symptoms were *possibly* due to MS. The highest number of ABR abnormalities found by Chiappa et al. (1980), was also in a group of patients diagnosed with *definite* MS. The physical severity of the disease (also described as the amount of disability the patient is experiencing) and the duration of the disease did not emerge as important factors in relation to the prevalence of ABR abnormalities (Jerger et al., 1986; Grénman, 1985).

- **The occurrence of disseminated lesions at several levels of the brainstem** (Keith & Jacobson, 1985). An increased number of ABR abnormalities have been associated with patients diagnosed with clinical and neurological (MRI) evidence

of brainstem involvement. Robinson and Rudge (1977) demonstrated ABR abnormalities in 79 % of patients with definite evidence of brainstem lesions and only 51 % abnormalities in those without clinical signs of brainstem disease. Chiappa et al. (1980) recorded similar findings.

Due to advanced technology and the availability of MRI, other investigators have compared the occurrence of brainstem lesions involving the auditory pathway (as detected by MRI) and the presence of ABR abnormalities. Levine et al. (1994) demonstrated ABR abnormalities in all of their patients displaying brainstem lesions in the auditory brainstem pathway. In a study performed by Antonelli et al. (1988) the ABRs of 32 patients with definite Multiple Sclerosis were contrasted with the brainstem anatomic lesions identified by MRI, and with neurological signs and symptoms of brainstem involvement found during the clinical examination. Twenty-one (65,5 %) of the 32 patients had abnormal ABR findings, which corresponded well with patients demonstrating abnormal MRI and/or signs of brainstem involvement. These results stress the need for combined neurological, ABR and MRI assessment of brainstem lesions in patients with Multiple Sclerosis, especially in cases where the disease is in an early stage. A correlation between findings of the ABR, MRI and that of the neurological examination can be drawn, when all these tests are performed concurrently.

- **Variations in the criteria used to describe ABR abnormality.** These variations ranged from the mean ± 2 / 2,5 / 3 standard deviation from the norm (Hall, 1992). Such differences can have a substantial effect on the estimated prevalence of ABR abnormalities.

- **Different procedures followed during the recording of ABRs.** This includes, different stimulus (also described as technical parameters) and acquisition (also described as procedural parameters) parameters.

Stimulus parameters

The effect of using different stimulus parameters (repetition rate and stimulus polarity) will be discussed according to reports in the literature:

- ***Stimulus repetition rates***

Some investigators suggested that ABR recordings were more sensitive to lesions caused by MS if the stimulus rates were increased (Antonelli et al., 1988; Jacobson et al., 1987; Musiek et al., 1989), although there was also evidence to the contrary (Jacobson & Newman, 1989; Chiappa et al., 1980). Due to demyelination, an increase in stimulus rate can adversely affect the central auditory synaptic function and neural refractoriness, thus altering the ABR results (Shanon et al., 1981). Jacobson et al. (1987) determined that faster repetition rates yielded an increased number of abnormal ABR latency measurements (absolute latency of Wave V and I-V interpeak latency), when compared to slower rates. They concluded that the number of abnormal ABRs increased as a function of increased stimulus rate and individual wave peak detection. It was found that a 67 per second stimulus rate produced the largest percentage of abnormal ABR recordings. As expected, wave peaks became more difficult to identify with increasing stimulus rates. Even though it was expected that alternation in stimulus rates would expose pathology, this manoeuvre only aggravated pathologies already apparent at slow stimulus rates (Elidan et al., 1982). Chiappa et al. (1980) also reported an insignificant difference in relative latency values between presentation rates of 10 and 70 clicks per second. Significant ABR changes did not appear at increased repetition rates. Jacobson and Newman (1989) reported similar findings when the effect of the interactions between stimulus rate and polarity was studied. These authors failed to show Wave I-V latency abnormality for rapid versus slow rates, using rarefaction polarity click stimuli. Increased stimulus rates also tended to reduce the clarity and the repeatability of recordings, therefore hampering interpretation.

On the other hand, Soudant et al. (1978) and Antonelli et al. (1986) observed a "less abnormal" ABR recording at increased repetition rates in some cases. Better synchronisation of the nerve at increased stimulus rates was given as a possible explanation for this phenomenon. Despite these findings, stimulus repetition rates are less reliable in determining ABR abnormality than absolute latency (Hood, 1998).

- ***Stimulus polarities***

In most ABR studies performed on patients with Multiple Sclerosis, only one click polarity was used (Jacobson et al., 1987; Jerger et al., 1986; Parving et al., 1981). The three alternatives during click polarity selection are rarefaction (R), condensation (C) and alternating (A) click polarities. The R click polarity was most frequently utilised, although the separate application of both R and C click polarities has generally been recommended (Hammond et al., 1986; Emerson et al., 1982; Maurer, 1985). Studies where both R and C click polarities were used, illustrated interesting findings. See Figure 2.1 for changes in ABR recordings when using the R click polarity.

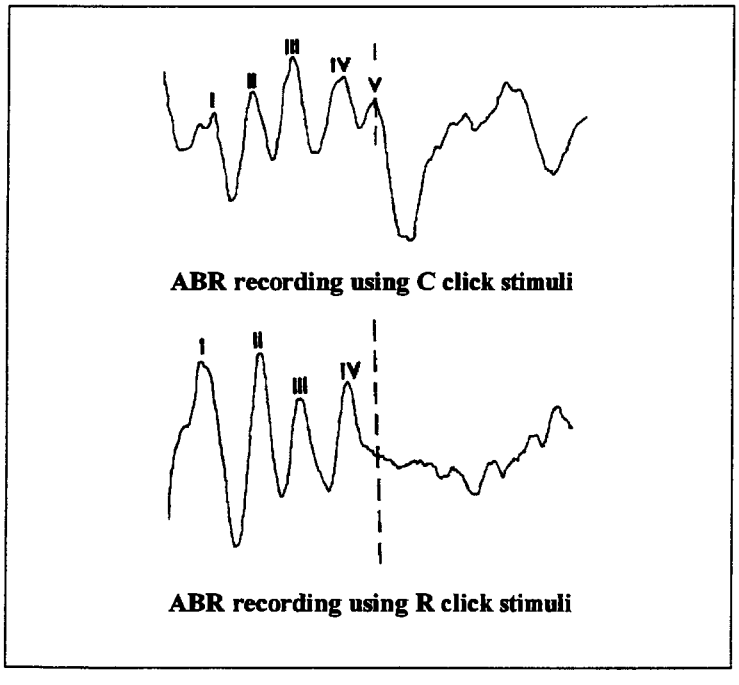

Figure 2.1: The absence of Wave V using R clicks (Chiappa, 1990:255)

Although Maurer (1985) reported nineteen ears with identical patterns of abnormality using either the R or C click polarity, twenty-one of the ears gave rise to different wave abnormalities dependent on the polarity of the stimulus. This indicated that there were patients with normal ABRs using one click polarity and pathological waves in the other. Hammond et al. (1986) reported an equal number of ABR abnormalities between both R and C click polarities, but different types of abnormalities were found in 40 % of the patients. Interpeak prolongation of waves, absence of Waves III and V as well as the absence of Wave V with the preservation of earlier waves, was found using both R and C click polarities. Similar findings were reported by Emerson et al. (1982); Sand (1991b) and Hammond et al. (1986). It was concluded that the two polarities could result in two different abnormal wave patterns, indicating different levels of lesions in the CANS.

It was recommended by Sand (1991a) that both the R and C click recordings did not have to be abnormal for the ABRs to be interpreted as abnormal, but rather that only ABR recordings using one polarity needed to be abnormal for such an interpretation to be made. By expecting recordings using both R and C click polarities to be abnormal may be more specific, but reduces the sensitivity of the test. These findings stress the importance of using both stimulus polarities consecutively, particularly if the initial ABR recording in one click polarity was normal.

Acquisition parameters

Another contributing factor leading to discrepancies between ABR studies, was the technique used in acquiring ABR recordings. Controversy exists in the literature on whether contralateral recordings are helpful in patients with Multiple Sclerosis. Contralateral ABR recordings increased the percentage of abnormality from 74 % (ipsilateral recordings) to 89 % (Quaranta et al., 1986). According to this study, contralateral recordings reproduced the abnormalities already present

during ipsilateral recordings, and also demonstrated that in a certain number of patients with normal ipsilateral ABRs it was possible to observe pathological contralateral responses. It was concluded that using the contralateral parameter increased the sensitivity of ABR recordings in terms of the detection of pathology. On the contrary Barajas (1982) did not find increased ABR abnormalities when using the contralateral parameter and Hammond and Yiannikas (1987) found that contralateral recordings were not especially helpful when performing ABRs on patients with Multiple Sclerosis. The use of contralateral recordings to detect ABR abnormality in MS has not been sufficiently conclusive to warrant use by all investigators (Jacobson & Jacobson, 1990).

The abovementioned factors have influenced the incidence and types of ABR abnormalities found between studies. Due to the high variability in ABR abnormalities reported, clinicians should not expect to find a homogeneous pattern of results in a patient population displaying such a varied distribution of lesions (Keith & Jacobson, 1985) with the auditory pathway being involved at several levels (Yamasoba et al., 1997). The ABR findings include response abnormalities of prolonged interpeak (I-III, III-V, I-V) latencies, decreased amplitudes (especially of wave V), poor morphology of later wave components; poor repeatability; total absence of one or more recognisable wave components after Wave I or II (most often Wave V); and occasional absence or prolongation of Wave I. The disparity between these different types of abnormalities is not easily explained by merely considering the known conduction deficits in demyelinated axons, such as slow conduction across the demyelinated segment in the increased refractory period (Chiappa, 1990). In some patients, absolute and interpeak latencies were statistically indistinguishable (deviates by four standard points) from the mean normal value. The pathophysiological implication is that the ABR recording can be normal in a given patient, if MS does not involve the auditory brainstem pathway. However even a small plaque in the auditory brainstem is enough to radically alter the neural conduction along the pathway (Hall, 1992; Chiappa, 1990). Table 2.1 summarises the different ABR abnormalities reported in the literature.

Table 2.1: Reported ABR abnormalities

Types and percentages of ABR abnormality	Researcher/(s)	Suggestions and possible reasons
THE ABSOLUTE LATENCIES		
Normal Wave I latency	Özünlü et al. (1998) Hausler & Levine (1980)	MS does not usually affect the peripheral portion of the auditory nerve where the myelin sheath is formed by Schwann cells rather than glial cells.
Delayed Wave I latency (2 to 10 % of cases)	Bergamaschi et al. (1997)	Possible demyelination of the cochlear nerve causing abnormal transmission of auditory input at the periphery.
Absent Wave I and latency delays (18 %)	Musiek et al. (1989)	In some MS cases the auditory nerve, even at its most distal segment, may be involved.
Abnormal absolute latency of Wave III (42,3 % of patients)	Musiek et al. (1989)	No possible reason was provided.
Abnormal absolute latency of Wave V (46,2 % of cases)	Musiek et al. (1989)	Anatomically, the presumed brainstem generators of Wave V are more likely to be compromised in patients with Multiple Sclerosis than those of Wave I (cochlear nerve).
THE PRESENCE OF WAVES		
Absent Wave III (25 % of patients)	Musiek et al. (1989)	No explanation was provided.
Wave V abnormalities (absent, low amplitude in 87 % of cases)	Chiappa et al. (1980)	No explanation was provided.
Absent Wave V (15,4 % of ears)	Musiek et al. (1989)	No explanation was provided.
AMPLITUDES OF WAVES		
Abnormal V/I amplitude ratios (21 % of cases)	Musiek et al. (1989)	It was suggested that amplitude ratio may be a valuable measure and may be a worthwhile inclusion criteria during the determination of ABR abnormalities.
Small Wave V amplitudes	Robinson & Rudge (1975) Starr & Anchor (1975)	The amplitudes of later waves are expected to be affected, as they are highly sensitive to brainstem pathology.
INTERWAVE LATENCIES		
I – III (11,1 %) III – V (14,3 %) I – V (25,6 %)	Musiek et al. (1989)	The high incidence of prolonged Wave I – V could relate to the high incidence of absent Wave III. More patients displayed III-V than I-III interpeak latency shifts, suggesting greater involvement of the central pontine pathways than the VIIIth nerve or peripheral ponto-medullary areas.
III – V (28 %)	Chiappa (1990)	The majority of conduction abnormalities were found to occur between the generators of Wave I (superior olivary complex) and Wave III (inferior colliculus), as would be expected, since this is the longest segment of white matter in the pathway being tested.

2.4.3 Findings of middle and late latency auditory evoked potentials

While the ABR reflects activity of the VIIIth cranial nerve and auditory brainstem, the middle-latency response (MLR) and late vertex response (LVR) reflect higher-level subcortical and cortical activity. The MLR and LVR have been used in conjunction with the ABR to assess higher levels of CANS function. In general it was found that the MLR and LVR are less likely to be abnormal when compared to the ABR, due to sclerotic lesions being relatively uncommon in the CANS (Stach & Hudson, 1990). The extent of cortical and high-level subcortical dysfunction, due to MS is not yet well defined (Stach & Hudson, 1990).

In spite of these uncertainties, evidence is mounting that MLR and LVR can in fact be abnormal as a result of MS. Robinson and Rudge reported abnormal MLR and LVR results as being 45 % and 5 % respectively, as far back as 1977. Abnormal MLRs were found in 40 % of patients diagnosed with Multiple Sclerosis in a study performed by Speershneider et al. (1986). Later a study was conducted by Stach and Hudson (1990) using ABR, MLR and LVR on 118 patients with definite Multiple Sclerosis. They found that at least one of the three evoked potentials was abnormal in 74 % of the patients tested. ABR was abnormal in 58 %, MLR in 47 % and LVR in 20 % of patients. The combination of ABR and MLR yielded the highest sensitivity to auditory involvement in patients with Multiple Sclerosis, while the LVR was found to be less sensitive.

There are many variables that need to be controlled during the recording of MLR and LVR. The patient's attention state and medication, which especially produces a central suppression of brain activity such as barbituates and chloral hydrate, will significantly influence and usually diminish the MLR and LVR (McPherson & Ballachanda, 2000). These variables can however be controlled when assessing adults with Multiple Sclerosis. Another influencing factor is that an abnormal MLR may simply be a reflection of the disordered lower brainstem (abnormal ABR) through which nerve impulses must pass. Thus the absence of an MLR may not be the result of a disorder at the generator site of

the MLR, but rather be the consequence of dysynchrony imposed by MS at a more peripheral (brainstem) site.

2.5 ASSESSMENT OF THE CENTRAL AUDITORY NERVOUS SYSTEM (CANS) OF PATIENTS WITH MULTIPLE SCLEROSIS

In an age of such sophisticated diagnostic tools such as computed tomography (CT) scanning and MRI, the need for neuro-audiological tests for the detection of CANS lesions can be questioned. However, audiometric test procedures are being used to describe the *functional status* of the auditory nervous system in patients with Multiple Sclerosis, while the radiological tools would yield data only on the *anatomical changes* of the CNS system. Furthermore, costs and availability of radiological or neurological procedures may be a factor, making central auditory assessment an appropriate choice. Although silent lesions are detectable with current radiological or magnetic imaging techniques, audiometric test procedures such as AR and ABR are also sensitive in detecting these lesions.

Another area where the audiometric assessment of the CANS is providing valuable information is during the monitoring of the neurological and auditory status of patients. In addition to this, CANS assessment can help document auditory function in patients with known CNS damage, if an auditory problem is suspected (Musiek & Lamb, 1994).

In the following section the findings of audiometric test procedures used during the assessment the CANS of patients with Multiple Sclerosis will be discussed.

2.5.1 Findings of central auditory processing (CAP) test procedures

CAP test procedures assess different anatomic regions and processes of the brain, which might be affected by the MS degenerative process. Rappaport et al. (1994) studied the temporal resolution capacity of 16 patients with Multiple Sclerosis, examining their

performances in gap detection and speech recognition in continuous and interrupted background noise. Temporal resolution is defined as "the ability to perceive or discriminate as separate events, sound segments spaced closely in time" (Stach, 1997:199). The role of temporal resolution in understanding speech in the presence of background noise is being recognised and studied increasingly in the field of audiology. Most patients with Multiple Sclerosis performed within normal limits, at all stimulus intensities during the gap detection testing. However, these patients displayed significant abnormalities under the interrupted masker of the speech-in-noise paradigm, confirming a temporal processing deficit. These performances suggested the predominant role of forebrain pathways in mediating auditory temporal resolution.

In 1990, Hendler et al. studied 15 patients with Multiple Sclerosis using two psychophysical tasks: the monaural gap detection and binaural masking level detection tests. The authors concluded that demyelinating lesions could cause deficits in temporal processing in the central auditory pathways, independent of the peripheral hearing status. Inferences were made that abnormalities at different levels of the auditory system could disrupt different types of temporal processing. Specifically, the gap detection performance was the least affected by the demyelinating lesions.

Musiek et al. (1989) used a battery of CAP tests on 27 patients with Multiple Sclerosis. The two most sensitive tests were: *masking level differences* (50 %), which is known for its sensitivity to lower brainstem/pontine lesions often present in patients with Multiple Sclerosis, and the *dichotic digits test* (33 %), which measures brainstem and cerebral auditory function. Other tests demonstrated less sensitivity: *frequency pattern test* (26 %), followed by the *staggered spondaic words test* (22 %), and only 7 % abnormality on the *low-pass filtered speech test.*

The above findings allude to the fact that only some CAP tests are more sensitive to lesions caused by MS and should be selected as part of the battery of test procedures. Musiek et al.'s (1989) study indicated that an extensive CAP test battery may not be necessary, and recommended the inclusion of two or three CAP tests (such as the masking

level differences and dichotic digits test) which are sensitive in detecting central auditory processing disorders (CAPD) in the MS population.

Although these tests are appropriate and efficient for assessing the CANS of patients with Multiple Sclerosis, there are certain limitations. One contributing factor is the complexity of the system under consideration (Musiek & Lamb, 1994). Even now the anatomy and physiology of the CANS is not completely understood, nor has its many different functions adequately been defined. Another factor is that MS frequently affects the peripheral brainstem structures, and sclerotic lesions with more central loci are relatively uncommon (Stach & Hudson, 1990). Finally there are only a limited number of standardised CAP tests available for clinical use in South Africa. Subsequently CAP tests were not included in the current study.

2.6 A MULTIPLE TEST BATTERY APPROACH USED IN PATIENTS WITH MULTIPLE SCLEROSIS

As discussed, many audiometric test procedures have been performed on patients with Multiple Sclerosis, but not without controversy and limitations. Some but not all of the limitations can be reduced if the auditory nervous system of patients with Multiple Sclerosis is assessed using a multiple test battery approach, selecting each test procedure to focus on a particular level of function (Hannley, 1986). In many instances auditory manifestations are so entwined that is difficult to separate the different areas using current test procedures. When considering the complexity of the auditory nervous system, it is understandable that only a limited number of tests are site-specific, although also dependent on the integration of other parts of the auditory nervous system. For example DPOAEs are dependent on the conductive mechanism and CAP tests are dependent on the conductive and sensory-neural mechanism of the ear. Therefore the existing lack of agreement in the literature regarding the definitions of sensory-neural, retrocochlear and neural disorders is understandable. This emphasises the fact that a multiple test battery approach that assesses all the components of the auditory nervous system is essential.

When using a multiple test battery approach to assess the auditory nervous system of patients with Multiple Sclerosis, the test battery needs to conform to several requirements. The battery of test procedures must be accountable during the interpretation of results, identifying auditory dysfunction on several levels and understanding the way in which the dysfunction affects the patient's hearing ability (Hannley, 1986).

2.6.1 Case history information

The importance of obtaining a case history has been indicated by Silman and Silverman (1991) as well as Grénman (1985). The case history provides the audiologist and/or medical practitioner with information regarding MS-related symptoms that the patient is experiencing on a subjective level. According to the literature the case history should include at least two components (Grénman, 1985; Daugherty et al., 1983). Firstly, the auditory symptoms associated with MS consisting of the patients' subjective perception of their hearing difficulties and communicative competence during every day life should be assessed. Questions regarding the presence of tinnitus should routinely be included. Secondly, the vestibular symptoms such as the presence of nystagmus, vertigo, balance disorders, and dizziness should be fully understood. Each component will be discussed in some detail.

2.6.1.1 Auditory symptoms associated with MS

Studies that included the patients' subjective perception of their hearing abilities illustrated discrepancies with their puretone findings. Grénman (1985) found a good correlation between patients' complaints of subjective hearing difficulty, and their impaired puretone thresholds. However, other studies reported that only 20 – 40 % of patients with impaired hearing thresholds complained of hearing difficulties (Von Leden & Horton, 1948; Bentzen et al., 1951; Von Preibisch-Effenberger, 1963). In a study performed by Rappaport et al. (1994) patients reported minimal complaints when listening in the presence of background noise. No correlation was found between these patients' complaints and their puretone thresholds. It has been documented that central and even

VIIIth nerve auditory deficits can exist with little or no compromise in puretone sensitivity. Musiek et al. (1989) also found a poor correlation between more than 40 % of patients presenting with subjective complaints of hearing difficulties, all had normal hearing sensitivity (thresholds equal or better than 25 dB HL, from 250 - 4 000 Hz). This finding may indicate that the patients' auditory symptoms were related to CNS dysfunction (specifically CANS dysfunction) and it was concluded that the patients' subjective perception of their hearing abilities provided information on the nature of their auditory problems.

Not all patients with Multiple Sclerosis mention a history of hearing difficulties although audiometric test procedures may confirm the presence of a hearing loss (Grénman, 1985). This indicates that patients' subjective perception of their hearing and communicative competence should be assessed in conjunction with a battery of other test procedures.

Due to the fact that hearing impairment is rarely an initial or prominent symptom of MS one can assume that tinnitus is not a common complaint often reported by patients. The occurrence of hearing loss with accompanying tinnitus, as an initial manifestation or during the course of MS is estimated to be less than 10 % (Fischer et al., 1985). Grénman (1985) found that 8,5 % of patients with Multiple Sclerosis complained of tinnitus and suggested that noise-induced hearing loss and presbyacusis may also have been the cause.

2.6.1.2 Vestibular symptoms related to MS

Only limited attention has been paid to vestibular symptoms even though these symptoms are associated with MS in more than 80 % of patients (Özünlü, 1998). It is therefore important to include questions regarding these symptoms as part of the case history. During the first formal description of MS, **nystagmus** was recognised as a salient feature of the disease (Charcot, 1877). Nystagmus is a rhythmic horizontal or rarely, vertical movements of the eyeballs that results from the anatomical connection between the vestibular and ocular systems (Hall, 1992; Stach, 1997). Nystagmus has been identified in 16 % to 70 % of affected patients (Grénman, 1985; Schweitzer & Shepard, 1989).

MS causes a variety of abnormal nystagmus including: spontaneous, lateral gaze and positional nystagmus; unilateral or bilateral caloric weakness and directional preponderance. These electronystagmography (ENG) findings were demonstrated within both the CNS and peripheral vestibular systems, as a result of plaques within the nerve root, where peripheral nerves contain CNS myelin (Keith & Jacobson, 1985). These lesions can also result in disequilibrium, ataxia and vertigo.

Vertigo has been reported as an initial symptom in only 5 – 12 % of patients with Multiple Sclerosis, with approximately 50 % of patients reporting vertigo during the course of their disease (Schweitzer & Shepard, 1989). Vertigo is a symptom resulting from brainstem and/or cerebellar lesions (Grénman, 1985). Lechtenberg (1995) found that vertigo is an uncommon symptom during the exacerbation of MS symptoms, and is more likely to develop in conjuction with a problem in the vestibular system of the inner ear than with a problem in the brain or brainstem. However, Grénman (1985) found that 51 % of the patients reported vertigo.

Another vestibular symptom related to MS, is the occurrence of **dizziness.** Lechtenberg (1995) found that dizziness is a fairly common symptom during a flare-up or exacerbation of MS symptoms. In contrast to this, Grénman (1985) found that only 7 % of his patients complained of dizziness and a falling tendency was reported by 21 % of the patients. Walking difficulty can be attributed to dizziness that can be described as a feeling of postural unsteadiness or light-headedness, but usually arises from problems with co-ordinating limb movements, namely ataxia. Unsteadiness, dizziness and vertigo have been found to be among the most common complaints during the course of the disease (Von Leden & Horton, 1948).

2.6.2 Basic test battery procedures

After obtaining a comprehensive case history, the second phase of the multiple test battery approach is performing the basic audiometric test battery. A multiple test battery approach must include the elements of the basic test procedures.

Puretone audiometry serves as the foundation of every audiometric assessment and is an essential part of the battery of tests (Hall, 1992). The basic test battery also includes speech audiometry and immittance measurements, and the findings during the assessment of patients with Multiple Sclerosis were supplied in Section 2.3. These findings of the basic test battery guide the audiologist in terms of patient management, such as medical referral, referral for speech-language testing, hearing aid evaluation, site-of-lesion assessment and counseling.

Due to the fact that a peripheral hearing impairment can confound the interpretation of ABR recordings used in neuro-otological assessment, it is vitally important to obtain a puretone audiogram before ABR testing. It was found that very few studies used puretone audiometry before recording ABRs. Since confident and accurate interpretation of any auditory evoked responses, such as ABR, usually requires at least some knowledge of middle ear and inner ear status, the basic test battery should be included during the assessment of patients with Multiple Sclerosis.

2.6.3 Site-of-lesion assessment

A multiple test battery approach has been effectively applied by researchers, such as Jerger et al. (1986) and Musiek et al. (1989) despite the diversity of the disease, uncertainties regarding symptom patterns, variations among patients, the complexity of the auditory nervous system, and the fact that MS can affect any part of the CNS. They concluded that no single test procedure was adequate during the assessment of neuro-otological disorders, such as MS. The results obtained from Musiek et al.'s (1989) study, suggested cortical or higher brainstem involvement and lower brainstem dysfunction (as assessed by ABRs and CAP test procedures). However the researchers concluded that the sensitivity of any combination of test procedures would be reduced, especially if the MS lesions did not affect the auditory pathway. One of the most significant findings of Jerger et al.'s (1986) study was the relatively high prevalence of auditory abnormalities found in patients with Multiple Sclerosis, and it was concluded that auditory testing was sensitive to the presence of MS. They did however not expand on the possible site-of-lesion involvement.

2.7 CONCLUSIONS

From the preceding overview on the nature of auditory involvement in patients with Multiple Sclerosis, certain implications for research can be deduced and implemented in the current study. Firstly, it was confirmed that MS could effect any portion of the auditory nervous system. An accurate description of the auditory function of patients with Multiple Sclerosis is dependent on a comprehensive assessment procedure. A multiple test battery approach assessing different levels of the auditory nervous system should be the focus of research. This multiple test battery approach has been applied in some of the research studies, and only partially in others.

In the light of the unresolved debate on the number of ABR abnormalities, further evaluation of several ABR parameters and recordings is necessary. The implementation of other test procedures, such as the self-assessment of patient's hearing abilities, associated auditory-vestibular symptoms and communication competence during every day life has also been partially assessed. The use of OAEs and CMs to assess the hair cell function of the cochlea is needed to determine whether pre-neural auditory involvement exists.

Further research on audiometric test procedures, such as puretone audiometry, DPOAEs, ABRs, and patients' subjective perception of their hearing abilities are necessary and can be conducted based on the knowledge that is presented in Chapter one and two. These audiometric test procedures should be used in combination in order to supplement each other. The multiple test battery should supply the researcher with sufficient information regarding the auditory functioning of patients with Multiple Sclerosis.

The assessment of the auditory nervous system and the treatment of hearing difficulties should be of growing interest in the field of audiology and neurology. Audiologists dealing with patients with Multiple Sclerosis must understand the nature of the disease and the rationale behind implementing a multiple test battery approach. Furthermore they must form part of multi-disciplinary team during the management of these patients.

2.8 SUMMARY OF CHAPTER 2

The goal of this chapter was to describe and discuss the signs and symptoms of auditory involvement associated with MS. This was followed by published results of test procedures used to assess the auditory nervous system of patients with Multiple Sclerosis. The elements of a multiple test battery approach were explained and research studies that have followed this approach were outlined.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 INTRODUCTION

It is evident from the previous two chapters that the nature and incidence of auditory involvement in patients with Multiple Sclerosis is influenced by various factors that are not yet clearly defined. It was illustrated that the disease is diverse in nature, resulting in a variety of audiometric patterns. The limitations of using a single test procedure were also outlined. It has been theoretically suggested that a multiple test battery approach would be the most effective, during the assessment of the auditory nervous systems of patients with Multiple Sclerosis. Although studies were conducted using a multiple test battery approach, certain limitations were identified.

The purpose of this chapter is to describe the research method implemented during the current study. The research method was compiled to meet the theoretical and clinical needs previously identified as essential during the audiometric assessment of patients with Multiple Sclerosis. The focus was on designing a battery of tests procedures sensitive in detecting sensory and neural auditory involvement. A practical and clinically appropriate battery of test procedures was selected for the assessment of the auditory nervous system of patients with Multiple Sclerosis.

3.2 AIMS OF THE STUDY

The aims of the research study were as follows:

3.2.1 Main aim of the study

The main of this study was to determine the clinical effectiveness of the selected battery of test procedures during the audiometric assessment of a group of adults with Multiple Sclerosis.

The following sub-aims were formulated in order to realise the main aim of the study.

3.2.2 Sub-aims

- ***Sub-aim 1***

  To describe the contribution of a self-assessment questionnaire in order to obtain information regarding the subjects' perception of their hearing abilities, auditory-vestibular symptoms and communicative competence during every day life.

- ***Sub-aim 2***

  To determine the contribution of puretone audiometry, DPOAEs and CMs to the multiple test battery, in order to describe the degree of hearing impairment (as assessed by puretone audiometry), as well as the type of hearing impairment in terms of sensory involvement (as assessed by DPOAEs and CMs).

- ***Sub-aim 3***

  To determine the contribution of ABR recordings using both R and C click polarities consecutively.

3.3 RESEARCH DESIGN

Leedy (1993:139) stated that: "The nature of the data and the problem for research dictate the research methodology. If the data is verbal, the methodology is qualitative, if it is numerical the methodology is quantitative". Due to the nature of the selected audiometric test procedures, both qualitative and quantitative research methodologies were utilised during the current study. Qualitative and quantitative data are compatible and can co-exist in a single study. Subjects were individually assessed using a multiple battery of test procedures and their audiometric results were described both quantitatively and qualitatively.

A combined *experimental-descriptive research design* was selected for the gathering of quantitative and qualitative data (Ventry & Schiavetti, 1980). "This research design often involves a within-subjects experimental study of the effect of an independent variable on a dependent variable with two different types of subjects" (Ventry & Schiavetti, 1980:105). The research was partly *descriptive* due to the fact the researcher selected subjects who fell into a pre-existing pathology. These subjects were described as the independent variable. Although all of the subjects had Multiple Sclerosis, they were divided into two groups. The *experimental* aspect of the study was the researcher's ability to select the audiometric test procedures (also described as the dependent variable), which included:

- the self-assessment questionnaire;
- puretone audiometry;
- DPOAEs including the CM; and
- ABR recordings using both R and C click polarities.

The following constant variables could be controlled, and were therefore excluded from the current study:

- presbycusis;
- poor co-operation;
- abnormal middle ear functioning and/or conductive hearing losses;
- evidence of middle ear surgery;

- ❖ use of ototoxic drugs; and
- ❖ history of trauma to head and/or ears.

3.4 RESEARCH SUBJECTS

Non-probability sampling, specifically *convenience/accidental sampling*, was selected for the current study. The advantage of non-probability sampling is that it is much less complicated and expensive than probability sampling. Another advantage of this sampling procedure is that it can be implemented on a spur-of-the-moment basis to take advantage of available participants, without the statistical complexity of probability sampling (Baily, 1994). Furthermore this type of sampling is indicated when only a small group of participants will suit the requirements of the study. The disadvantage of non-probability sampling is that the researcher cannot claim that the sample is representative of the larger population and generalisation of findings beyond the sample cannot be made (Leedy & Ormrod, 2001).

3.4.1 Subjects

Subjects with definite Multiple Sclerosis were the focus of this study. Subjects were recruited from the South African National Multiple Sclerosis Society as well as from a neurologist. A notice concerning the research project was published in the South African MS Society's newsletter, asking members to participate in the study. Despite this, most of the subjects were obtained via word of mouth. All volunteering participants who met the inclusion criteria for subject selection formed part of the sample. The study's rating panel consisted of two additional audiologists selected by virtue of their clinical experience in diagnostic assessment.

3.4.1.1 Criteria for subject selection

Subjects were required to meet the following criteria (as confirmed by audiometric testing and/or self-reporting in the administered self-assessment questionnaire), in order to be included in the study:

❖ **Diagnosis of Multiple Sclerosis**

All subjects had to be diagnosed by their physician or neurologist with definite Multiple Sclerosis, prior to the study. The diagnosis requires that the patient be of an appropriate age and experienced at least two episodes of neurological disturbance implicating two distinct sites of involvement in the CNS (McDonald & Silberberg, 1986).

❖ **Age**

Subjects were required to be between 20 and 50 years of age, as the study focused on adults with Multiple Sclerosis. The reason for this is firstly, because MS typically begins in the second or third decade of life, and is rarely diagnosed in children under the age of 15 or in adults over the age of 55 (Noseworthy et al., 2000). In order to assess hearing impairment exclusively caused by MS, normal deterioration of hearing sensitivity as a function of age, needed to be ruled out.

❖ **Language proficiency**

All subjects were required to be proficient in English or Afrikaans, since the self-assessment questionnaire and instructions during the actual testing were presented in either of these two languages. Competence in either of the two languages was required in order to minimise misinterpretation of information.

❖ **Co-operation of subjects**

Only subjects who were able to co-operate for approximately two and a half hours were included in the study. Due to the fact that patients with Multiple Sclerosis often experience fatigue, sensitivity to heat, spasticity as well as bowel and bladder problems, resting periods were given during the assessment. If a subject seemed to be in an acute exacerbation (relapse) phase during the audiometric testing causing discomfort and/or inattentiveness, he or she was excluded from the study.

❖ **Gender**

Gender was not a selection criterion, due to several reasons. MS has a female predominance of approximately 2:1 (Noseworthy et al., 2000). Therefore an unequal number of female and male subjects were acceptable. Gender effects on DPOAEs are apparently limited to minor differences in DPOAE amplitudes and thresholds (Lonsbury-Martin et al., 1990). Although small differences have been found between the ABR findings of females and males, the clinical importance of this fact is generally minimal due to the substantial normal variability (Hall, 1992). The published norms for ABR findings used in the current study were developed from a population that included both males and females (Bio-Logic System Corporation Evoked Potential User's Manual, 1993).

❖ **Normal middle ear functioning**

Due to the fact that any conduction problem caused by a middle ear pathology would influence the accuracy of the puretone thresholds, DPOAEs and ABR recordings, normal middle ear functioning was required. Normal middle ear functioning was determined by performing an otoscopic examination and tympanometry.

Otoscopic examination of the external auditory meatus was important to determine if the ear canals were not occluded with excessive cerumen or debris. This can affect the puretone thresholds and block the otoacoustic emission microphone, preventing the accurate measurement of the DPOAEs. The second aspect investigated was the tympanic membrane. The absence of perforations and the presence of a light reflection on the tympanic membrane were viewed as indicative of a healthy tympanic membrane (Hall & Chandler, 1994).

A subject's **tympanometry** results had to be within the following specifications for inclusion in the study:

A *Type A tympanogram* was one of the criteria indicating normal middle ear functioning. Jerger's (1970) classification system for single-component, low probe-

tone frequency (226 Hz) tympanograms was used. A Type A tympanogram has a peak (point of maximum admittance) near normal atmospheric pressure, within the range of 0 to -100 daPa. The peak can actually be slightly positive, for example, +25 daPa. *Normal static immittance* values, when measured at 226 Hz and described as compliance of an equivalent volume of air, range approximately from 0.30 - 1.60 cm^3. *Normal ear-canal volumes* as determined for adults, range from 0.65 - 1.75 cm^3 (Hall & Chandler, 1994).

❖ **Medical and otological history**

In order to ensure that hearing impairment and auditory-vestibular symptoms were related specifically to MS, participants' using drugs that are ototoxic to the cochlea and vestibular system, were excluded from the study. Drugs that are ototoxic to the ear and can cause a hearing impairment, include certain antibiotics, salicylates, quinine, cis-platinum, aminoglycosides (including gentamycin, streptomycin and tobramycin), selected diuretics (furosemides), analgesics (aspirin), antihypertensives (reserpine) and antiarrhythmics (quinidine) (Ginsberg & White, 1994). Medications that have been reported to produce symptoms of tinnitus in isolation or in combination with hearing impairment include agents such as erythromycin, lidocaine, reserpine, furosemide and lithium (Stach, 1997). Participants using any of these listed drugs when the case history information was obtained and/or during the administration of audiometric test procedures were excluded from the study.

❖ **Other causes of hearing loss**

Participants were excluded from the study if they reported a history of trauma to the head and/or ear/(s) and/or middle ear surgery seeing as this can result in the presence of a sensory-neural and/or conductive hearing loss. On the other hand, participants who were exposed to single episodes or continuous high levels of noise either using hearing protectors or not, were included in the study. Noise exposure was not controlled as one of the constant variables since the sample size was already relatively small and excluding these subjects would have resulted in an even smaller

sample. Furthermore audiologists are bound to assess patients with Multiple Sclerosis who have a history of noise exposure. Probably an audiologist will seldom encounter a patient with symptoms and auditory involvement exclusively due to Multiple Sclerosis. *The results of these subjects were presented separately.

3.4.1.2 Subject selection procedures

The procedure through which subjects were finally selected consisted of the information obtained from the self-assessment questionnaire (see Appendix C), followed by an otoscopic examination of the external meatus and tympanic membrane, as well as tympanometry.

The self-assessment questionnaires were mailed to all participants who volunteered telephonically to participate in the study. A cover letter explaining the purpose of the study and what the study would involve accompanied the questionnaire. General instructions for the completion of the questionnaire were included (see Appendix C).

Participants had to complete a consent form and return it to the researcher with the completed questionnaire. The information obtained from the questionnaire was used to determine whether participants met the inclusion criteria developed for the study and to confirm their candidacy. Sections A and B of the questionnaire were designed to yield biographical and case history information about the participants and their disease. Questions regarding age, time of diagnosis, MS classification and medication currently in use were contained in these sections. Questions regarding noise exposure, head and/or ear trauma, etc. were answered in Section C. All variables, other than the diagnosis of MS that could negatively affect participants' hearing sensitivity were identified and those participants were excluded from the study.

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*It can be expected that these subjects would demonstrate impaired hearing sensitivity, subjective complaints of difficulty with hearing and cochlear involvement. Most of the subjects demonstrated abnormal puretone thresholds due to cochlear involvement, but did not complain of hearing difficulties. The hearing losses were of a mild degree and not steep and the expected ABR abnormalities found with high-frequency hearing losses were not often observed. Thus the fact that these subjects were exposed to noise prior to the study could explain cochlear involvement, but not necessarily neural involvement.

Those participants, who met the criteria for inclusion in the study, were informed telephonically. An audiometric assessment was then scheduled. During the scheduled assessment the answers provided in the self-assessment questionnaire were discussed and elaborated on to ensure that all data provided was accurate and that the questions were clearly understood. Subsequently the otoscopic examination and tympanometry were performed.

3.4.1.3 Description of subjects

The final sample consisted of 25 subjects (50 ears) with Multiple Sclerosis, 17 females and 8 males, which correlated with the female predominance of 2:1 (Noseworthy, 2000). Their ages ranged from 31 to 49 years, with a mean age of 41,6 years. One participant was excluded from the study as he presented with a congenital hearing impairment. The high incidence of relapsing-remitting MS, compared to other courses of the disease correlated with the literature (Noseworthy, et al., 2000). See Table 3.1 for an individualised description of the sample.

Table 3.1: Description of subjects

NO	AGE	SEX		YEAR OF DIAGNOSIS	YEAR OF INITIAL SYMPTOMS	COURSE OF SYMPTOMS	RACE	ORIGIN
		Male	Female					
GROUP 1								
1	46		X	1999	1996	RR	W	SA
4	43		X	1995	1995	RR	W	SA
5	39		X	1981	1980	SP	W	SA
6	39		X	1999	1999	RR	W	SA
8	36		X	1988	1983	RR	W	SA
9	34	X		2001	2000	U	W	SA
11	39		X	1996	1978	U	W	SA
15	48		X	1986	1969	B	W	SA
16	39		X	1991	1979	SP	W	SA
17	39	X		1994	1993	RR	C	SA
18	37		X	1988	1980	RR	W	SA
19	49		X	1989	1987	RR	W	SA
20	31		X	1997	1996	SP	W	I
22	45		X	1992	1985	U	W	SA
25	46		X	1986	1982	SP	W	SA
GROUP 2								
2	48		X	1994	1994	U	W	SA
3	46		X	1992	1986	RR	W	I
7	39	X		1990	1985	PP	W	SA
12	43	X		1987	1987	RR	W	SA
13	41	X		1998	1993	RR	W	SA
14	46	X		1990	1982	RR	W	SA
21	46	X		U	1980	U	W	I
23	41		X	1990	1983	U	W	SA
24	48		X	2000	1997	U	W	SA
26	34	X		1998	1997	RR	W	I

Course of Symptoms (See Appendix B)

RR	= Relapsing-remitting
SP	= Secondary progressive
PP	= Primary progressive
B	= Benign
U	= Uncertain

Race	W	= White
	C	= Coloured
Origin	SA	= South African
	I	= Immigrant

Figure 3.1 illustrates the age and gender distribution of the subjects across six age intervals of five years each.

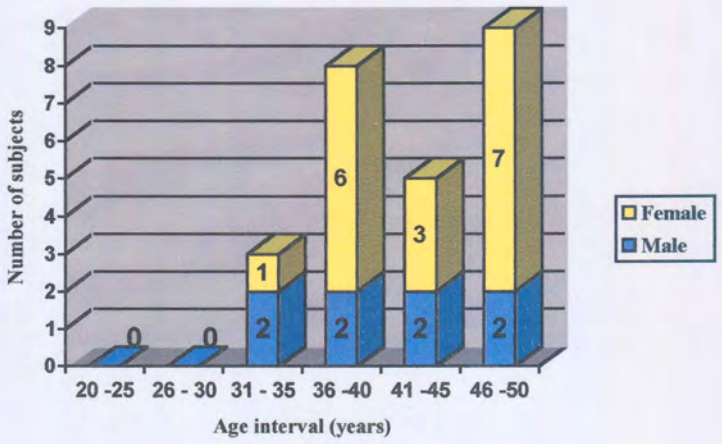


Figure 3.1: Age and gender distribution of subjects

The subjects were categorised into two groups. Group 1 consisted of 15 subjects (30 ears) with Multiple Sclerosis who had no history of exposure to high levels of noise. Group 2 consisted of 10 subjects (20 ears) with Multiple Sclerosis, who had at some time been exposed to single episodes or continuous high levels of noise. Only two of the ten subjects made use of hearing protectors.

Figure 3.2 illustrates the time lapse between the medical diagnosis of MS and the current study across five intervals of five years each.

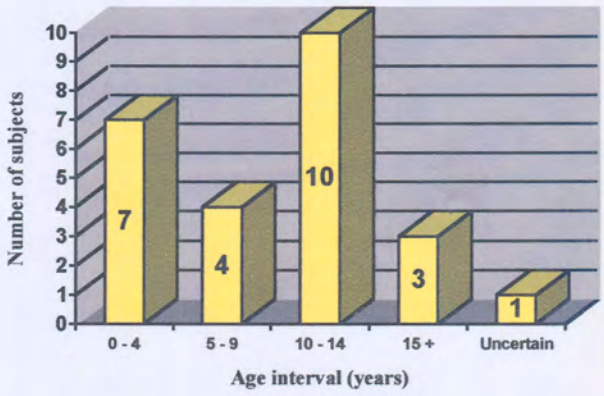


Figure 3.2: Time lapse between the medical diagnosis and the current study

Both groups' time of diagnosis ranged from the same year when the study was performed to 20 years before the study, with a mean range being 8 years, 2 months prior to the current study.

Figure 3.3 illustrates the time lapse between first experiencing MS related symptoms and the medical diagnosis across five intervals of five years each.

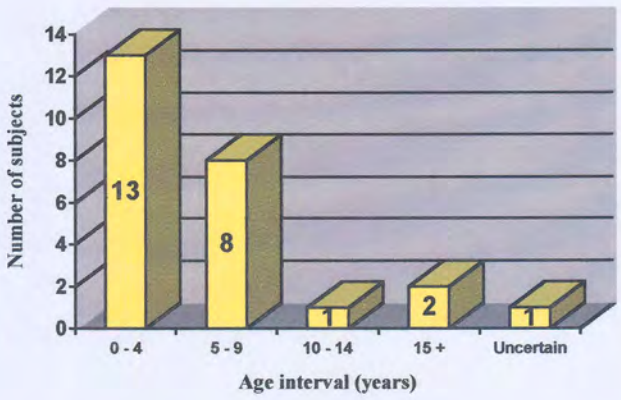


Figure 3.3: Time lapse between first experienced MS-related symptoms and the medical diagnosis

Most of the subjects noticed their MS related symptoms several years before the diagnosis. For some subjects, MS related symptoms were experienced up to 18 years before diagnosis. The mean time lapse between initial MS related symptoms and time of diagnosis was 5,3 years for Group 1; 3,8 years for Group 2, and 4,7 years across both groups.

No Indian or Black subjects formed part of the study, which correlated with the low prevalence of MS in these ethnic groups (Rivera, 1990). Four subjects were born outside the Republic of South Africa and immigrated before the age of 15 years. Immigrants moving from a high-risk to a low-risk area (such as from England to South Africa) carry with them the risk factor for increased MS prevalence provided they immigrated over the age 15 years (Rivera, 1990). Seeing as the four subjects in the current study immigrated to South Africa before the age of 15 years, the high-risk factor can be excluded.

It was interesting to note that in this relatively small group of subjects, six reported family member/(s) with Multiple Sclerosis. Although there is no conclusive evidence that MS is directly inherited, it has been found to develop 12 to 15 times more readily in relatives of affected individuals than in the population at large (Rivera, 1990).

3.4.1.4 Rating panel

The rating panel consisted of two additional clinical audiologists.

3.5 MATERIAL AND APPARATUS

The material and apparatus used for this study can be categorised in three sections, namely: subject selection material and apparatus; data collection material and data collection apparatus.

3.5.1 Subject selection material and apparatus

- The self-assessment questionnaire was sent to the subjects prior to the actual audiometric assessment and included questions to determine whether participants met the criteria for subject selection. See paragraph 3.5.2, Table 3.2 and Appendix C for a description of the self-assessment questionnaire.

- A Welch Allyn 2.5 model otoscope was used to examine the external meatus and tympanic membrane of each subject.

- A Grason Stadler Instrument TympStar version 2 Middle Ear Analyser that is calibrated annually was used for tympanometry.

3.5.2 Data collection material

❖ Several questions were included in the self-assessment questionnaire for the purpose of data collection. The data obtained included the subjects' perception of their hearing abilities, auditory-vestibular symptoms and communicative competence during every day life. Different questions and response formats were included in the questionnaire:

Open-ended questions were added and had to be completed with written answers. Coding errors can however occur when the researcher misinterprets open-ended responses. Therefore answers provided were verified during the interview.

A list of likely answers was provided in the **closed-ended response format** and participants were instructed to indicate which of the answers applied to them. The advantages of closed-ended questions are that they reduce the number of vague or ambiguous answers that might be given, and respondents can usually answer these items quickly (Breakwell et al., 1997). The disadvantage of this format is that it can create artificially forced choices and rule out unexpected responses. Therefore, the choices of all the closed-ended response questions were reviewed by two participants during the preliminary study. The following closed-ended response formats were included in the self-assessment questionnaire:

- *Categorical response format,* where participants could indicate only one possible answer, was used particularly for the collection of biographical information.
- *Multiple-response items,* where participants were expected to select the appropriate answer from approximately three possibilities, for example "yes", "sometimes" or "no".
- *Rating scales* were included and participants had to mark three- and four-step rating scales for example the Rating Scale for Each Ear (RSEE) and Communication Complaint List (COM-C).

The specific areas and aims of the self-assessment questionnaire is summarised in Table 3.2.

Table 3.2: Collection of data using a self-assessment questionnaire

AREAS AND AIMS OF THE SELF-ASSESSMENT QUESTIONAIRE	DESCRIPTION OF QUESTIONS	MOTIVATION AND SOURCES
SUBJECT SELECTION	Section A, Question 7; Section B, Questions 12,16 and 17; Section C, Question 19.	To determine whether participants met the inclusion criteria. Most of the questions were derived from Silman & Silverman's (1991) case history information format.
SELF-ASSESSMENT OF RELATED MS SYMPTOMS -Initial MS related symptoms -Auditory-vestibular symptoms	Section B, Question 15 Section C, Questions 20-23	To compare the presence of hearing difficulties, tinnitus and vertigo as part of the initial MS related symptoms, to those reported during the study. To determine the presence of tinnitus, dizziness and vertigo during the study (Daugherty et al., 1983).
SELF-ASSESSMENT OF HEARING ABILITY -Unilateral and bilateral -The nature and onset of the hearing difficulties	Section D, Questions 24-27	The information obtained from the RSEE (Schein et al., 1970) was used to compare subject's self-perception of their hearing abilities with their puretone findings as well as the results from other audiometric test procedures.
SELF-ASSESSMENT OF COMMUNICATIVE COMPETENCE	Section E, Question 31 (10 items) Two items were added: "Do your family and/or friends say you have a hearing problem?"; and "Do you experience difficulty localising the direction of sound?"	Communication Complaint List (COM-C), Schow et al. (1990).
COMPARING HEARING DIFFICULTY WITH OTHER MS RELATED SYMPTOMS AND THE EFFECT ON QUALITY OF LIFE	Section E, Question 32 and 33	To determine how subjects rated their hearing difficulties as compared to other MS related symptoms as well as the effect on their quality of life (Klugman, 2000).

3.5.3 Data collection apparatus

- Puretone audiometry was performed in a soundproof booth, within a sound treated room suitable for threshold determination. The soundproof booth met the SABS:0182 specifications for background noise levels. The test signal was delivered with a Grason Stadler Instrument Clinical Audiometer (GSI 61) and transduced in a set of TDH-50P supra-aural headphones and Radioear B-71 bone vibrator. The audiometer is calibrated annually in accordance with the SABS 0154-1:1996 specifications.

- The Bio-logic System Brainstem Auditory Evoked Potential was used for the ABR recordings. These recordings were performed in a soundproof booth with the subjects lying on a bed. The stimuli were presented through Etymotic Research ER-3 insert earphones. A Hewlett Packard LaserJet 6L was used for printing purposes.

- The measurement of DPOAEs was conducted with a Grason Stadler Instrument (GSI 60) Distortion Product Emissions. The probe was calibrated for a quiet room in September 2001, in accordance with the SABS 0154-1:1996 specifications.

Puretone audiometry and ABR recordings were performed in the same soundproof booth, while DPOAEs were conducted separately in a sound treated room.

3.6 PROCEDURES

The following procedures were utilised in the various stages of the research project:

- The procedures followed during the preliminary study.
- The procedures followed during the collection and recording of data.
- The procedures followed during the analysis of data.
- The procedures followed during the processing of data.

3.6.1 Preliminary study

Two participants with definite Multiple Sclerosis (of relapsing-remitting and primary progressive course) volunteered to be part of the preliminary study. Both participants met the criteria developed for subject selection.

The purpose of the preliminary study was to:

- Evaluate the suitability of the self-assessment questionnaire.
- To determine stimulus and configuration parameters of DPOAEs.
- To determine the stimulus and acquisition parameters of ABRs.
- To determine the required time for the completion of all the test procedures for a single participant, in order to plan the data collection procedures.

3.6.1.1 Determination of the suitability of the self-assessment questionnaire

Two participants were given trial self-assessment questionnaires to obtain feedback on the length, format, ease of answering questions, level of complexity and general instructions of the questionnaire. The questions and answers were given to one participant orally, because he was blind.

The following suggestions were incorporated:

- "Bladder problems" was included in the list of associated symptoms of MS in Section B, Question 15.
- A column for "reason for using medication" was provided next to "medication" listed at Section B, Question 17.
- A space was provided after each item at Section C, Question 19 for subjects to provide particulars, if they answered "yes".
- Several options for possible answers were provided in Section C, Question 26, instead of requesting the date or time when difficulties with hearing had first been noticed.

3.6.1.2 Determination of optimal stimulus and configuration parameters for DPOAEs

Two distortion product "audiograms" (DPgrams) were obtained for each ear in order to determine the repeatability of the responses. The normative database, Vanderbilt 65/55 sample of Normal Ranges was selected (Hornsby et al., 1996). This normative DPOAE data was originally collected from young, normal hearing adults (hearing levels of 15dB HL or better from 250 - 8 000 Hz, and Type A tympanograms) in a quiet, but not sound-treated room. The amplitude of the distortion product was plotted as a function of the f_2 frequency.

The same stimulus and configuration protocols as developed for the Vanderbilt 65/55 Normal Ranges were used during the preliminary study. See Tables 3.3 and 3.4 for further details.

Table 3.3: DPOAE stimulus protocol

Intensity:	L1= 65 dB SPL	L2 = 55 dB SPL
DP frequency range:	562 - 6250 Hz	
Number of octaves:	4	
Number of points/octave:	6	
Frequency ratio:	1.2	
Sampling rate:	32 000 Hz	

Sourced from: Hall (2000:562)

Table 3.4: DPOAE configuration protocol

Frame rejection criteria	Single-frame noise level: absolute noise > 35 dB SPL
	L1 or L2 out of tolerance: ± 5 dB SPL
	Test time: ≥ 400 frames
Total rejection conditions	Noise level exceeded: ≥ 50 frames
	L1 out of tolerance: ≥ 20 frames
	L2 out of tolerance: ≥ 20 frames
Test acceptance conditions	Minimum accepted frames: ≥ 10 dB SPL
	Absolute average noise: ≤ -6 dB SPL
	DP amplitude - average noise floor: ≥ 10 dB SPL
	Average absolute noise: ≤ -12 dB SPL

Sourced from: Hornsby et al. (1996:44)

During the preliminary study the stimulus and configuration protocols were slightly varied, in order to determine their applicability and practicality for the current study. The following changes were made:

Table 3.5: DPOAE protocol settings for the current study

PROTOCOL	PRESCRIBED SETTING	SETTINGS FOR CURRENT STUDY	MOTIVATION
Stimulus	6 DP points per octave (amounts to 22 frequency pairs)	3 DP points per octave (amounts to 12 frequency pairs)	Decreased test time and sufficient information regarding DPOAE presence between test frequencies.
Configuration	DP amplitude minus average noise floor ≥ 10 dB SPL	DP amplitude minus noise floor ≥ 5 dB SPL	The DP amplitude must exceed the noise floor (NF) by at least 5 dB SPL for a DP point to be considered as present (Hall, 2000).

The stimulus and configuration protocols that were adapted for the current study were accepted as being sufficient for the purpose of assessing the subjects' cochlear function.

3.6.1.3 Determination of optimal stimulus and acquisition parameters for ABRs

Due to the significant variability of abnormal ABRs found in patients with Multiple Sclerosis, special attention was paid to the selection of stimulus and acquisition parameters, since these factors could influence the outcome of ABR recordings (Hood, 1998). The adult ABR normative data published in the Bio-Logic System Corporation Evoked Potential User's Manual, developed at the Boys Town National Institute for Communication Disorders was used during the preliminary study, since published norms were not yet available at the current place of assessment (University of Pretoria) at the time of the study. When using published normative ranges, Hood (1998) recommended the use of the same stimulus and acquisition parameters as those implemented to establish the normative values. Subsequently, the same stimulus and acquisition parameters applied to develop the Boys Town ABR normative data were used during the preliminary study. The only exception was that one-channel, instead of two-channel recordings were

used since contralateral recordings during the detection of ABR abnormality in MS has not been sufficiently conclusive to justify use by all researchers (Jacobson & Jacobson, 1990). See Table 3.6 for a full description.

Table 3.6: ABR stimulus and acquisition parameters

STIMULUS PARAMETERS	
Type	Click
Duration	100 msec
Rate	13/sec
Polarity	Rarefaction
Intensity	80 dBnHL
Transducer	Beyer DT48
ACQUISITION PARAMETERS	
Amplification	100,000
Electrodes	Fz-to-ipsi lateral mastoid, with non-test ear as ground
Filter settings	100 - 3 000 Hz
Notch filter	None
Filter slopes	6 dB/octave
Analysis period	10,24 or 15,36 msec
Number of sweeps	1 024; two replications

Sourced from: User Manual of Bio-Logic System Corporation Evoked Potential (1993:E3)

The ABR results obtained during the preliminary study were as follows:

- The ABR recordings of the first participant displayed poor wave morphology and waves were difficult to identify in the right ear at 80 dBnHL with a stimulus rate of 13 per second. The intensity level was increased to 90 dBnHL, but even poorer wave morphology was present. Thereafter the stimuli were presented at a rate of 67.7 per second at 80dBnHL, but waves could still not be identified. No repeatable waves could be obtained from the left ear due to increased artifacts. Even though the participant was sleeping, the electromyography (EMG) was high and reliable recordings could not be obtained. Patients with Multiple Sclerosis experience muscle spasms especially in their legs, which may influence the amount of artifacts measured. According to Hood (1998) patients with Multiple

Sclerosis may also display spontaneous nystagmus, even when their eyes are closed. Nystagmus could result in high EMG activity during ABR recordings.

- The ABR click stimuli for the second participant was presented at 80dBnHL, also at a low stimulus rate of 13 per second. Reliable tracings of Waves I and II were recorded at 80 dBnHL and 90 dBnHL. However, no reliable tracings of later waves could be obtained in the right ear due to high artifacts caused by EMG activity. The participant was instructed to open his eyes, but this only increased the number of artifacts. After a rest period of 15 minutes recording was discontinued as the artifacts continued to accumulate.

After conducting the preliminary study the following suggestions were made and implemented for the current study:

- More time should be scheduled for ABR recordings. Testing should be paused when artifacts accumulate and the researcher must wait for the EMG activity to reduce before continuing the recordings.
- If increasingly high artifacts are present, subjects should be instructed once again to lie still and not move their bodies, eyes or jaws. If nystagmus is suspected, subjects should be advised to open their eyes and fixate on an object.
- When no reliable ABR recordings can be obtained due to increasingly high artifacts, this should be recorded as a no response (NR).

On the basis of the results of the preliminary study and recommendations from the literature, stimulus and acquisition parameter adjustments were made. Parameters such as the intensity, stimulus polarity, transducer, electrode placement, number of sweeps and replications were adjusted.

See Table 3.7 for a summary and discussion of the stimulus and acquisition parameters utilised during the current study.

Table 3.7: ABR parameters for the current study

Parameter	Prescribed setting	Settings for current study	Motivation
Stimulus polarity	Rarefaction	Rarefaction and Condensation	The type of stimulus polarity influences the shape and normalcy of the ABR recordings (Tackmann & Vogel, 1987). Due to the discrepancies found when reversing the click polarity it is recommended that both R and C click polarities be presented consecutively (Sand, 1991b; Maurer, 1985; Emerson et al., 1982). When the polarity (R and C) of the click phase is reversed, the waves also invert resulting in the presence of the cochlear microphonic (CM). The presence of the CM assists the researcher in the identification of Wave I, especially when the stimulus artifact is enlarged. The presence of the CM (prior to Wave I) in the absence of waves can be indicative of auditory neuropathy (Hood, 1998).
Stimulus intensity	80 dBnHL	80, 90 & 70 dBnHL	During the application of ABRs for neurological purposes the click stimuli need to be presented at an intensity level well above threshold, usually between 70 and 80 dBnHL (Hood, 1998). The first ABR recording will be obtained at 80 dBnHL. If a clear response is not obtained, the intensity will be increased to 90 dBnHL. If a clear response is still not obtained, the stimuli will be decreased to 70 dBnHL.
Transducer	Headphones (Beyer DT48)	Insert earphones (ER-3)	The use of insert earphones is recommended due to the fact that Wave I is easier to identify (stimulus artifact is separated from the onset of the response) in most instances, ear collapse is prevented and interaural attenuation is increased. Insert earphones are more comfortable for longer periods of time, which may assist in reducing the artifacts (Hood, 1998).
Acquisition (number of sweeps)	1 024; two repetitions	2 000; two to three repetitions	Due to an increasingly high number of artifacts found in the preliminary study, it was decided to increase the number of sweeps to 2 000. As the number of sweeps is increased, the background noise (caused by EMG, EEG activity and 50 Hz noise) decreases, making the ABR waves more visible (Hood, 1998). When two recordings are repeatable testing will be discontinued. If repeatability cannot be found after two recordings a third recording will be obtained using 2000 sweeps. Up to three recordings of 2 000 sweeps each will be allowed.
Acquisition (filter settings)	100 - 3 000 Hz	300 - 3 000 Hz	Increasing the high-pass filter setting usually eliminates low-frequency electrical and electrophysiological noise, including EEG (Hood, 1998).
Acquisition (electrode placement)	C_z-to-ipsilateral mastoid with forehead as ground (2-channel montage)	F_z-to-ipsilateral mastoid with non-test ear as ground (1-channel montage)	Ipsilateral recordings were most often used in the clinical setting where the study was performed. There are many controversies in the literature whether contralateral recordings in patients with Multiple Sclerosis yields more information than ipsilateral recordings. Barajas (1982) illustrated that the number of ABR abnormalities did not increase using contralateral recordings, but only redefined those abnormalities present when using ipsilateral recordings.

3.6.1.4 Determination of the time required to complete all measurements

In order to schedule appointments with future subjects the test battery was performed during the preliminary study to determine the amount of time that will be required for the assessment of each subject. As seen in Table 3.8 the complete assessment lasted for approximately two and a half hours for each participant. More time was required in some instances, especially when ears demonstrated hearing impairment and puretone bone conduction thresholds had to be obtained. In the presence of increased artifacts extended testing time was required due to increased averaging, in order to obtain repeatable tracings.

Table 3.8: Approximate time required for the assessment of one participant

Review completed questionnaire	15 minutes
Otoscopic examination	5 minutes
Tympanometry	10 minutes
Puretone audiometry	15 minutes
DPOAEs	15 minutes
ABRs	1 hour, 30 minutes
Total testing time	**2 hours, 30 minutes**

3.6.2 Data collection and recording procedures conducted during the study

In order to describe the audiometric findings of future subjects it was necessary to collect data from the self-assessment questionnaire, puretone audiometry, DPOAEs and ABRs (including the presence of the CM).

3.6.2.1 Procedures followed for the self-assessment questionnaire

As mentioned in paragraph 3.5.1 the self-assessment questionnaire, cover letter and consent form were mailed to every participant who volunteered to be part of the study, prior to the actual audiometric assessment. An instruction sheet was included with the questionnaire.

The participants were reminded telephonically in cases where questionnaires had not been returned within three weeks after they had been sent. Despite the fact that five participants did not return the questionnaire, the return rate was higher than 80 %.

3.6.2.2 Procedures followed during puretone audiometry

Each subject was seated in a soundproof booth and was given the following instructions: "I will now place the earphones on your ears. You will hear pulsing tones, first in the right ear and then in the left ear. Please press the button every time you hear the tone, even if it is very soft."

If subjects presented with impaired air-conduction thresholds, only those subjects with sensory-neural hearing losses (no gap between air and bone conduction thresholds) were accepted for the study. Puretone thresholds were determined according to the preferred technique based on the Carhart-Jerger modified Hughson-Westlake method (Hall & Mueller, 1997; GSI 61 User Manual, 1996). Thresholds for air and bone conduction puretone audiometry were plotted on an audiogram for each ear separately. The standard symbol system for audiograms developed by the American Speech-Language-Hearing Association (Roeser et al., 2000) was used.

3.6.2.3 Procedures followed during DPOAEs

DPOAEs were performed directly after the completion of puretone audiometry. Subjects were seated facing the GSI 60 DPOAE system and the procedure was explained briefly by making a statement such as: "For this test I'm going to place a soft tip into your ear canal. Once it is in place, you'll hear some tones. They won't be loud. Pay no attention to these sounds. You don't have to tell me that you hear the sounds. This test should only take a minute or two for each ear. Please just sit still and relax during this time. I'll let you know as soon as the test is completed."

First, the stimulus and configuration protocol was selected and subsequently a new file was opened for each subject. Thereafter the probe was inserted into the external meatus assuring a snug fit within the ear canal.

During the recording of the DPgrams the noise floor levels were monitored visually on the computer screen. DPgrams were repeated if the noise floor levels were above the prescribed norm. The DPgrams were repeated at least twice for each ear to increase reliability. Hall (2000) recommended that the absolute distortion product (DP) amplitude values should be reasonably similar from one DPgram to the next (e.g. ± 2, 3, 5 dB). Before performing a second DPgram the probe tip was removed from the ear canal and replaced. This once again ensures a proper fit (Hall, 2000). The two DPgrams were superimposed for rapid evaluation of repeatability. Every DPgram consisted of twelve frequency pairs and every frequency pair consisted of two puretones, f_1 and f_2, presented to each ear simultaneously. The twelve frequency pairs were presented in sweeps, one at a time, starting with the low frequencies and ending with the high frequencies. The stimulus ratio between the two frequencies (f_2/f_1) was 1,20. Four DPgrams were saved for each subject.

3.6.2.4 Procedures followed during ABRs

One-channel recordings, using a three-electrode montage, were used for recording ABRs. The forehead electrode (F_z) was positioned in the midline on the forehead approximately at the hairline. Electrodes were also positioned on the mastoids of each ear. The left electrode site is referred to as A_1 and the right electrode site as A_2. The non-test ear's electrode served as the ground electrode. The wave tracings were plotted in the vertex-positive direction, with the vertex upward.

The following instructions were given to each subject once they were lying on the bed in the sound proof booth: "You will hear loud clicking sounds, first in the one ear and then in the other, but you do not have to respond". Subjects were encouraged to relax and even sleep.

Electrodes were applied by first cleaning the surface of the skin where the electrodes were to be placed. The forehead and mastoids were scrubbed with a commercial prepping solution and wiped off with an alcohol-soaked gauze pad. The electrode discs were filled with conductive paste and applied to the prepared sites. Silver-plated disc

electrodes were securely attached with tape. After a file had been opened for each subject the electrode impedance was measured. Impedance should be below 5 000 ohms for all electrodes combined, and fairly equal (within about 2 000 ohms) between electrodes sites (Hood, 1998). Electrode impedance was checked after the insert earphones had been positioned for testing and also periodically during testing, as any changes in impedance could affect the quality of the recordings.

First, the stimuli consisting of R clicks (100 msec duration) were presented monaurally through a pair of insert earphones at a rate of 13 per second at 80dBnHL. White noise for masking the contralateral ear was presented at 60dBnHL if an asymmetrical hearing impairment was present during puretone audiometry. In an average response 2 000 sweeps were required. The same collection procedure was followed during the presenting of C click stimuli. Responses were recorded and analysed by using an average-response computer. All responses were repeated twice or, if necessary three times at each intensity level. This would increase the consistency of the recordings. Responses were amplified 100 000 times and the band-pass filters were set at 300 Hz for the high-frequency noise and at 3 000 Hz for the low-frequency noise at 6 dB per octave. Responses were averaged by using a 10,24 msec analysis window.

3.6.3 Data analysis procedures

3.6.3.1 Analysis of audiometric results by a panel of audiologists

The audiograms, ABR recordings and DPgrams together with the Spreadsheets on Microsoft Excel were handed over to the panel of audiologists. These audiologists are familiar with the analysis of the selected test procedures. The interpretation of results was verified and consensus between both audiologists represented a positive criterion.

3.6.3.2 Analysis of data obtained from the self-assessment questionnaire

During the development of the self-assessment questionnaire a coding information column "For office use" was included. A respondent number was allocated to each

subject's completed questionnaire and a variable number was allocated to each data item or question. Every answer supplied at each variable was coded in the information area. The coded information was supplied to the data analyser for computer analysis.

The commercially available rating scale (RSEE) and questionnaire (COM-C) were analysed as follows:

- To determine how the subjects rated their hearing abilities in **both ears** the prescribed analysis format for the RSEE was used (Schow et al., 1990). The four item rating scales for each ear were scored as follows:
  1 = "good hearing";
  2 = "little trouble hearing";
  3 = "a lot of trouble hearing"; or
  4 = "I am deaf".
  Ratings from both ears were combined in the following arrangement: 1 & 1 = 1; 1 & 2 = 2; 1 & 3 = 3; 1 & 4 = 4; 2 & 2 = 5; 2 & 3 = 6; 2 & 4 = 7; 3 & 3 = 8; 3 & 4 = 9, and 4 & 4 = 10. A combined score of 1 or 2 on the RSEE constituted a pass. A combined score greater than 2 constituted a fail.

- No prescribed method for the analysis of data gathered from the COM-C could be obtained from the literature. The researcher developed a method for analysing this data. Three out of twelve items (one, two and four of Section E, Question 31) were selected to determine the extent of subjects' communicative competence during every day life. Answers "yes" or "sometimes" were interpreted as indicative of communication difficulties.

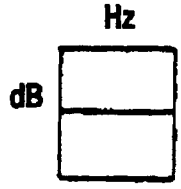
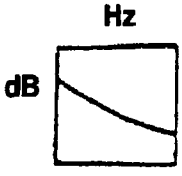
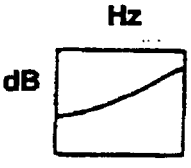
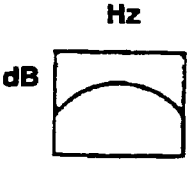
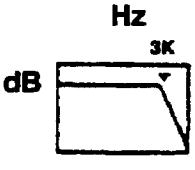
3.6.3.3 Analysis of data obtained during puretone audiometry

The results obtained during puretone audiometry were used to make the initial diagnosis of normal or abnormal hearing sensitivity. For the purpose of this study, normal hearing sensitivity was described as thresholds within the 0 – 20 dB HL range, across all frequencies tested (125 – 8 000 Hz) (Jerger & Jerger, 1980). Abnormal hearing sensitivity was defined as any threshold below 20 dB HL, at any given frequency tested.

It should be noted that the average threshold level (determined according the ANSI-1989 method) was not calculated. Determining an averaged puretone threshold may result in some ears being interpreted as displaying normal hearing sensitivity, while the thresholds in the very low and/or high-frequency range may be elevated.

The abnormal audiograms were categorised according to the configurations illustrated in Table 3.9.

Table 3.9: Audiometric configurations

TERM	DESCRIPTION	AUDIOMETRIC CONFIGURATION
Flat	A hearing loss greater than 20 dB HL across the frequency range 250 – 4 000 Hz, and thresholds at each frequency are within 5 to 10 dB HL from each other.	
Sloping	As the frequency increases, the degree of hearing loss increases. It is characterised by hearing losses greater than 10 dB HL in the higher frequencies, compared to the low frequencies.	
Rising	As the frequency increases, the degree of hearing loss decreases. Thresholds are better in the higher frequencies. The hearing loss is at least 10 dB HL or more in the low frequencies, compared to the high frequencies.	
Dome-shaped	The greatest hearing loss is in the low and high frequencies, and hearing sensitivity is better in the mid frequencies.	
High frequency	The hearing loss is limited to the high frequencies ranging from 4 000 to 8 000 Hz.	
Other	If the audiometric configuration could not be categorised according to the above mentioned, it was categorised and described as "other".	

Sourced from: Dayal et al. (1970:328) and Roeser et al. (2000:247)

After puretone thresholds were analysed the quantitative data was organised, and entered into the Microsoft Excel Spreadsheet to simplify later processing of data.

3.6.3.4 Analysis of data obtained during DPOAEs

Once a valid and reliable DPgram was obtained for each ear the analysis was performed. At this stage in the clinical development of DPOAEs there is no "preferred method" for analysis (Hall, 2000). Guidelines developed by Hall (2000) were used for DPOAE analysis and are displayed in Table 3.10.

Table 3.10: DPOAE analysis strategy

STEP	RATIONALE
Analyse each test frequency separately.	Take advantage of the frequency specificity offered by DPOAEs.
Does DP amplitude exceed noise floor?	DP amplitude must exceed the noise floor (NF) to be considered present. Minimal criterion set for the study is a DP – NF difference ≥ 5 dB. This does not imply that the DP is normal, only that it is detectable.
Calculate absolute DP amplitude.	If the DP amplitude (ignoring the NF) exceeds some minimum limit, such as > -10 dB, it is probably not due to physiological activity from the cochlea, but rather noise from either the environment or the OAE device.
Is the DPOAE data repeatable?	The DP amplitude values should be reasonably similar from one DPgram to the next (e.g. ± 2 dB or 3 dB). There are no accepted guidelines for DP reliability.
Is DP amplitude within the normative region?	DPOAE interpretation must be performed with reference to an appropriate normative database. The Vanderbilt 65/55 normative database was selected for the current study. The DPOAE will be recorded with a protocol similar to the Vanderbilt 65/55 normative data. DPOAE data versus normative data was interpreted as a function of stimulus frequency.

Adapted from: Hall (2000:140)

During the analysis of the DPgrams the three DP points per octave, in each of the four octaves (0.5 – 1 kHz; 1 – 2 kHz; 2 – 4 kHz and 4 – 8 kHz) were analysed separately. According to Hall (2000) the analysis of DPOAEs will lead to one of three general outcomes, implemented as follows during the current study:

- Outcome one: The DPOAEs were entirely normal.
  If one DP point per octave (3 points per octave) fell below the accepted level the DPgram was still analysed as normal.

- Outcome two: The DPOAEs are reduced or abnormal.
  No distinction was made between a DP point being reduced or absent. Both of these findings were analysed as abnormal. For a DPgram to be analysed as abnormal, two or three DP points per octave, in all four octaves had to be below the normal range.

- Outcome three: This outcome is a combination of the first two.
  If two or more DP points in a specific octave fell outside the normal range, that octave was analysed and described as being abnormal.

The results of the DPOAEs were analysed according to the above outcomes and the data was entered into the Microsoft Excel Spreadsheet.

3.6.3.5 Analysis of data obtained during ABR recordings

ABR waveforms were recorded for each ear, using both polarities (R and C) consecutively. The waveforms were analysed according to several parameters:

- Waves I, III and V were defined as individual waves being present, which meant it could be easily identified between other waves. Reduced amplitudes resulted in waves being analysed as doubtful.
- The repeatability of Waves I, III and V was analysed as either acceptable or poor. Acceptable repeatability of waves meant that two out of the three tracings of that particular wave were repeatable, as rated by the panel of audiologists.
- Absolute latency of Waves I, III and V was calculated in msec from the onset of stimulus to the peak of the wave.
- Interpeak latency Wave I-III, III-V and I-V was measured between wave peaks.
- Interaural Wave V latency difference refers to the difference of the absolute latencies of Wave V between the two ears.

- The cochlear microphonic is an inverted response prior to Wave I, when the click polarity is reversed. The CM was analysed either as being present or absent. It was described as being *present* when the potential inverted in all of the traces (in the same ear) and as a*bsent* when no inversion was found after reversing the click polarity.
- The Wave V/I amplitude ratio was calculated by dividing the amplitude of Wave V by the amplitude of Wave I, and if the ratio was less than 1,0 μV it was analysed as abnormal (Hood, 1998). The amplitudes of both Wave I and V was measured from the peak to the trough of each wave. The ratios of both the R and C click polarities were recorded.

The absolute and interpeak latencies were classified as abnormal if they were not within the limits of the following published normative data.

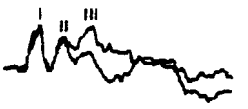
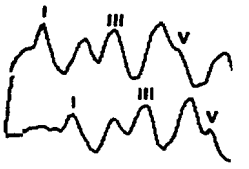
Table 3.11: Normative data used for ABR analysis

	LEFT EAR				RIGHT EAR		
	Mean	**SD**	**± 2,5 SD**		**Mean**	**SD**	**± 2,5 SD**
I	1,54 ms	0,12 ms	1,24 – 1,82 ms	I	1,27 ms	0,11 ms	1,27 – 1,82 ms
III	3,69 ms	0,10 ms	3,44 – 3,94 ms	III	3,67 ms	0,12 ms	3,37 – 3,67 ms
V	5,54 ms	0,19 ms	5,07 – 6,01 ms	V	5,52 ms	0,22 ms	4,97 – 6,07 ms
I – III	2,14 ms	0,23 ms	1,57 – 2,71 ms	I – III	2,13 ms	0,14 ms	1,78 – 2,48 ms
III – V	1,86 ms	0,14 ms	1,51 – 2,21 ms	III – V	1,85 ms	0,17 ms	1,43 – 2,27 ms
I – V	4,00 ms	0,20 ms	3,5 – 4,5 ms	I – V	3,98 ms	0,19 ms	3,51 – 4,45 ms

Sourced from: User Manual of Bio-Logic System Corporation Evoked Potential (1993:E8)

The ABR recordings were analysed as abnormal when one or both ears (using either the R or C click polarity consecutively) displayed one or more of the following:

Table 3.12: Examples of ABR abnormality

ABR ABNORMAL WHEN:	EXAMPLE
1. Wave I/III/V was absent or doubtful. Possible reason: ❖ The pathological condition may be severe enough to disrupt (conductive blocking of neural transmission) the generation of components of the ABR (Arnold, 2000).	
2. The repeatability of Waves I/III/V was poor. Possible reason: ❖ Desynchronisation resulting from neural plaque formation may contribute to this common finding in MS (Jacobson & Jacobson, 1990).	
3. The absolute latencies of Waves I/ III/ V deviated from the mean ± 2,5 SD. Possible reason: ❖ Waves are delayed due to a mild form of demyelination causing transmission delays (Jacobson & Jacobson, 1990).	
4. The Wave I-V/ I-III/ III-V interpeak latencies deviated from the mean ± 2,5 SD. Possible reason: ❖ The IPL is a measure of brainstem transmission time. The IPL of waves become prolonged as the auditory system is more involvement due to the combination of temporal (neural desynchronisation) and neural dispersion (Jacobson & Jacobson, 1990)	
5. The interaural Wave V absolute latency difference was greater than 0,4 msec (Hood, 1998). Possible reason: ❖ Due to brainstem lesions affecting the auditory pathways resulting in changes of Wave V absolute latency.	
6. The amplitude ratio of Wave V/I was less than 1.0 μV (Hood, 1998). Possible reason: ❖ Combined temporal dispersion and neural delays may result in the reduction of wave amplitudes especially of Wave V (Jacobson & Jacobson, 1990).	

Adapted from: Arnold (2000); Hood (1998); Jacobson and Jacobson (1990)

The CM is one of two cochlear potentials evoked by sound. It is an alternating current potential arising mainly from outer hair cells, although there may be limited inner hair cell contribution (Hall, 2000). Dallos and Cheatham (1976) stated that CMs were potentials generated by activation of both inner and outer hair cells, and their absence is indicative with impaired hair cell function. Mechanisms underlying the production of the CM are may involve velocity or acceleration of hair cell movement and displacement of the basilar membrane. Withnell (2001) found that the CM was recorded from the round window and is dominated by cellular generators located at the base of the cochlea.

The presence or absence of the CM was compared to that of the DPOAEs. One might question the need for including both DPOAEs and the CM in the multiple test battery, as both of these measurements determine the cochlear hair cell activity. In the current study the CM was not analysed as part of the EcochG, but rather as part of the ABR recordings. The analysis of the CM was valuable when used in cohesion with a battery of other test procedures since ABR abnormality in the presence of observable DPOAEs, and CMs were indicative of auditory nerve involvement in the presence of normal cochlear hair cell function (Starr et al., 2001).

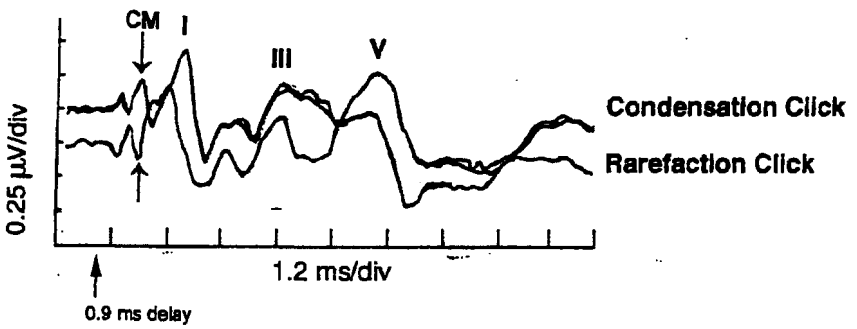


Figure 3.4: The presence of the cochlear microphonic (Hood, 1998:54)

After the ABR waveforms for both ears were recorded the pre-programmed Graph Master (Protocol 1) was used during the analysis and interpretation of latencies in comparison to normative data boundaries. The GraphMaster is a time saving tool for evoked-potential data interpretation and its curves represent a range of ± 2.5 standard deviation from the mean.

To increase the reliability of data analysis and interpretation, all of the ABR waveforms were handed over to two clinicians familiar with the interpretation of ABR measurements when using different click polarities.

All the ABR recordings, using both polarities consecutively, were categorised and presented in figures or tables for each group according to the aforementioned examples. The data was entered into the Microsoft Excel Spreadsheet for analysis.

3.6.4 Data processing procedures

The coded information of the self-assessment questionnaire was captured utilising a computer package (Statistical Analysis System). The printed information was given to the researcher to locate any errors. Errors were corrected and checked by the researcher for a second time. The data was statistically analysed to obtain frequency distribution presented in forthcoming figures or tables.

All the prepared data organised on the Spreadsheets was converted statistically to recognise trends and patterns in the results. This was illustrated by using graphic representations and frequency tables. Correlations between test scores were calculated. No statistical tests, for example, the "t-test", were justified.

3.7 SUMMARY OF CHAPTER 3

This chapter provided a thorough description of the procedures implemented in the research methodology to acquire the data according to the sub-aims, in order to address the main aim of the study. The need to determine the contribution of a multiple test battery approach in a group of adults with Multiple Sclerosis, in order to determine the clinical usefulness of these test procedures was the driving force behind this research. The research design was outlined followed by the selection criteria and description of subjects used in the current study. The material and apparatus used for the selection of subjects and the collection of data was subsequently discussed, followed by the procedures for data collection and recording as well as analysis procedures utilised during the realisation of the three sub-aims. The chapter was concluded by an overview of the data processing procedures implemented during the current study.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

The results will be discussed based on the main aim of the study, describing and examining the results obtained from a selected battery of test procedures performed on a group of adults with Multiple Sclerosis, in order to determine the clinical appropriateness of the multiple test battery. These results were addressed through the realisation of three closely related sub-aims. The purpose of the first sub-aim was to determine the contribution of a self-assessment questionnaire as part of the multiple test battery. The second sub-aim was to determine the puretone thresholds as well as cochlear function, and its contribution as part of the multiple test battery. The third sub-aim was to examine the contribution of ABR recordings using R and C click polarities consecutively. This sub-aim was followed by a description of the discrepancies and similarities of different types of ABR abnormalities when reversing the click polarity.

The purpose of this chapter is to present the results of this study according to the three sub-aims, in order to address the main aim of the study. The results are presented and discussed by integrating the current body of knowledge, and extracting the significance of results obtained. The results for each sub-aim will be presented, followed by an interpretation and discussion alongside current literature. In the final section of this chapter a summary of results as obtained from the multiple test battery, in realisation of the main aim, will be supplied.

4.2 DESCRIPTION AND DISCUSSION OF RESULTS: SUB-AIM ONE

To determine the contribution of a self-assessment questionnaire developed to obtain information regarding the subjects' perception of their hearing abilities, auditory-vestibular symptoms and communicative competence during every day life.

Results will be discussed in terms of subjects' reported initial MS-related symptoms prior to their diagnosis as well as, and opposed to, the self-assessment of related hearing abilities, auditory-vestibular symptoms and communicative competence during every day life, at the time of the current study.

4.2.1 Reported initial MS-related symptoms prior to the actual diagnosis of MS

Subjects reported the following symptoms as part of their initial MS-related symptoms prior to the actual diagnosis of MS:

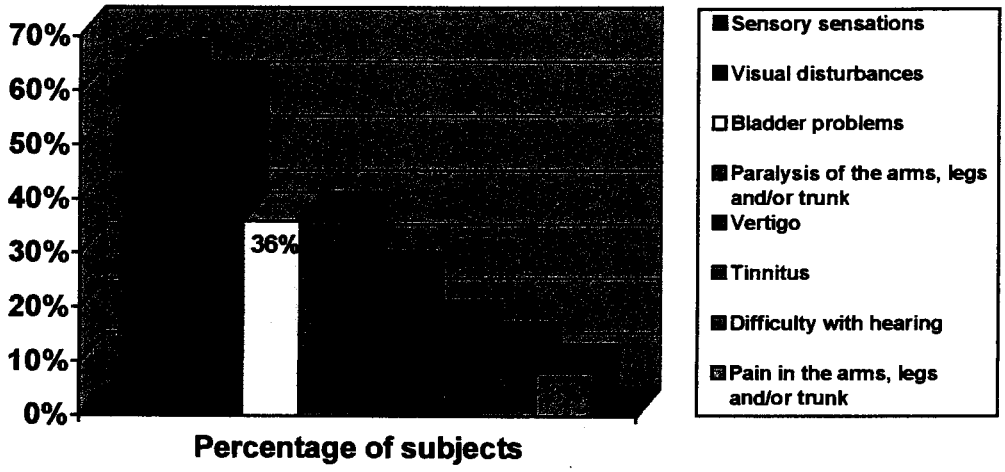


Figure 4.1: Initial MS-related symptoms

Compared to the other related symptoms of MS, **tinnitus** and **difficulty with hearing** were reported by a relatively small number of subjects. Daugherty et al. (1983) found that patients do not complain of hearing difficulties possibly due to other more invalidating MS-related symptoms.

Four subjects who reported the presence of tinnitus and/or difficulty with hearing had also been exposed to single episodes and/or continuous noise, thus MS might not have been the only cause of these symptoms.

Only a small percentage of subjects reported **vertigo** as one of their initial MS related symptoms, as also noted by McAphine et al. (1972). These numbers can be expected to increase during the course of the disease due to increased involvement of the peripheral nerve, cerebellum and/or vestibular nuclei as the disease progresses (Grénman, 1985).

It was concluded that loss of hearing and related auditory-vestibular symptoms were not clinically significant as part of the initial MS- related symptoms.

4.2.2 Reported auditory-vestibular symptoms during the time of the study

The prevalence of symptoms such as tinnitus, vertigo, dizziness and difficulty with hearing during the time of the current study were reported as follows:

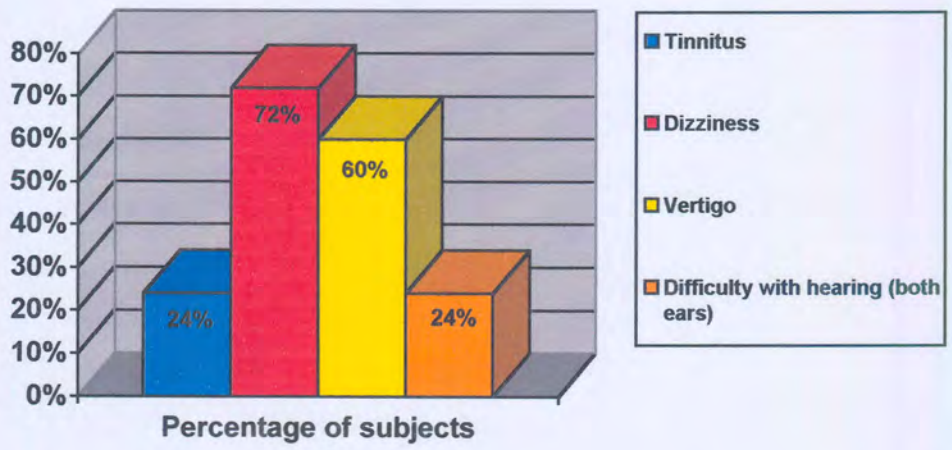


Figure 4.2: Auditory-vestibular symptoms reported during the current study

A high percentage (72 %) of subjects experienced **dizziness** or a feeling of light-headedness. Most of the subjects described their dizziness as a balance disturbance and a feeling of being unsteady. This may be a form of weakness or co-ordination problem resulting from cerebellum lesions. However dizziness may also attribute to balance disturbances (Lechtenberg, 1995). Other descriptions obtained were "feeling dizzy" during a MS relapse, or experiencing a "floating feeling". Some subjects reported that their dizziness occurred when their activity level increased or during exposure to heat. It is a known fact that MS symptoms will worsen during exposure to heat (Lechtenberg, 1995). The percentage of subjects who reported the presence of dizziness was similar to that found by Müller (1949), where 78 % of patients experienced balance abnormalities and 32 % a feeling of giddiness. According to McAlpine et al. (1972) "giddiness" or "dizziness" is as common as "true vertigo" in patients with Multiple Sclerosis.

The prevalence of reported **vertigo** increased during the course of the disease (from 25 % to 60 %). Grénman (1985) found this to be a typical symptom related to MS. According to Keith and Jacobson (1985) approximately 50 % of patients report vertigo at some time during the course of the disease, whereas Martin (1981) found that vertigo can occur in as many as 75 % of patients. The reason for this might be related to the specific area of pathology caused by MS. True vertigo possibly has its origin in the labyrinth, VIIIth nerve (vestibular portion), or vestibular nucleus (Barbour, 1985). Less common causes of vertigo include lesions of the cerebral cortex, cerebellum and the oculomotor apparatus (Barbour, 1985). It is well known that the vestibular nerve (Ylikoski & House, 1981), as well as the vestibular afferent pathways (Robinson & Rudge, 1977) can be involved in the demyelinating process resulting in vertigo. Von Leden and Horton (1948) also found that reported symptoms such as unsteadiness, dizziness and vertigo are among the most common complaints during the course of the disease, irrespective of the pathophysiological background. This was also the case in the current study.

Due to the high percentage of subjects who experienced dizziness and vertigo at a later stage of the disease, and the fact that these vestibular symptoms may be the result of VIIIth nerve involvement, it can be concluded that questions regarding these symptoms need to be included in the self-assessment questionnaire.

The prevalence of **tinnitus** experienced before the diagnosis of MS was low, but the percentage increased to 24 % during the current study. More subjects belonging to Group 1 (not exposed to noise) reported the presence of tinnitus. According to the literature tinnitus is a rather uncommon complaint in patients with Multiple Sclerosis (Grénman, 1985). Nishida et al. (1995) reported that the frequency of tinnitus as an initial symptom or during the course of the disease has been estimated to be less than 10 %. Grénman (1985) found that only 8,5 % of patients (including those previously exposed to high levels of noise) complained of tinnitus while an even lower percentage was reported by Klugman (2000) and Kahana et al. (1973). These low percentages were interesting to note since this auditory symptom has been associated with demyelinating diseases (Lechtenberg & Shulman, 1984). However, a higher percentage was present during the current study. Tinnitus is most often caused by a dysfunction of the cochlear apparatus, but may also be as a result of a dysfunction in the cochlear nucleus or more central auditory pathways (Barbour, 1985). The two subjects in Group 2 who reported tinnitus had been exposed to high levels of noise, thus complicating the isolation of the cause.

Although most of the subjects in both groups rated their **hearing abilities** as *good* in both ears, a small percentage (24 %) of subjects indicated that they experienced *little trouble* with hearing in both ears. This percentage was equally distributed between the two groups. Thus exposure to noise could only be a possible contributing factor in half of these cases.

The six subjects (both groups) who rated their hearing abilities as affected to some degree, for both ears, made the following statements regarding the *onset of the hearing loss*:

- three subjects were of the opinion that the onset of their hearing loss was gradual;
- two were uncertain; and
- one subject reported a sudden loss of hearing.

The latter subject presented with a unilateral mild to moderate sensory-neural hearing loss. Although sudden loss of hearing sensitivity has been reported in the literature, this

finding is rare (in about 1 % of patients) (Bergamaschi et al., 1997). Furthermore it must be kept in mind that the presence of MS does not preclude the likelihood of a sudden hearing loss resulting from other causes (Stach et al., 1990).

The six subjects who experienced some degree of hearing difficulty described the *nature of the hearing loss* as follows:

- one subject was of the opinion that the hearing loss remained constant;
- one was of the opinion that the hearing loss was progressive;
- two observed fluctuating hearing losses; and
- two were uncertain.

Despite the above mentioned subjects commenting on the onset and nature of the hearing losses, another two subjects who rated their hearing abilities as *good* in both ears, made the following statements:

- one subject believed that the hearing abilities had gradually worsened over the past 2 years and a fluctuating hearing loss was in fact perceived; and
- the other subject experienced difficulty with hearing at a later stage during the course of the disease.

These two subjects were not included in the percentage as illustrated in Figure 4.2, because they provided conflicting information.

According to the literature, difficulty with hearing is not a common or prominent complaint in patients with Multiple Sclerosis (McAlpine et al., 1972). However the percentage of subjects rating some degree of hearing difficulty in the current study was higher than Müller's (1949) 4 % and Noffsinger et al.'s (1972) finding of approximately 7 % of patients. Rappaport et al. (1994) reported that none of their patients had significant hearing complaints, despite the fact that some of these patients demonstrated mild high-frequency hearing losses when tested. Grénman (1985) found that only six patients reported impaired hearing ability in both ears (including patients being exposed to noise). However Klugman (2000) reported that 23,3 % of patients experienced difficulty with hearing in both ears, which correlates with the findings of the current study.

The relatively low prevalence of both tinnitus and hearing difficulties seemed to be consistent with the literature accumulated over the last 55 years. These symptoms are dependent on the site of lesion/(s) and may in some instances not be perceived by the patients themselves, but may only be identified through appropriate audiometric testing. Subjects' self-perception of the auditory symptoms should be included as part of the self-assessment questionnaire considering that it can provide valuable information, but should not be used in isolation.

4.2.3 Communicative competence at the time of the study

The following section will discuss subjects' self-assessment of their communication competence during every day life, as experienced at the time of the current study. As stated in Chapter 3, items no. 1, 2 & 3 were pre-selected for analysis purposes.

Table 4.1: Self-assessment of communicative competence

Types of communication complaints	Number of subjects (percentage)	
	Group 1 = 15 subjects	Group 2 = 10 subjects
1. People mumble	10 (66,66 %)	6 (60 %)
2. Asking for repetition	11 (73,33 %)	6 (60 %)
3. Hearing words, but not understanding	4 (26,66 %)	3 (30 %)
4. Difficulty hearing in background noise	11 (73,33 %)	7 (70 %)
5. Difficulty hearing from another room	8 (53,33 %)	7 (70 %)
6. Difficulty hearing when face not visible	6 (40 %)	6 (60 %)
7. Not hearing the ringing of telephone	3 (20 %)	2 (20 %)
8. Need to turn up volume of TV/ radio	8 (53,33 %)	5 (50 %)
9. Difficulty hearing while using the telephone	4 (26,66 %)	2 (20 %)
10. Family noticed hearing problem	1 (6,66 %)	3 (30 %)
11. Avoids social events	2 (13,33 %)	0 (0 %)
12. Difficulty localising the sound source	8 (32 %)	3 (30 %)
Analysis of items no 1, 2 and 4	**(71,06 %)**	**(63,3 %)**

Despite the fact that a high percentage of subjects rated their hearing abilities as *good* in both ears, a relatively high percentage of subjects (both groups) were of the opinion that they often had to ask for repetition, experienced difficulty hearing in the presence of background noise, and that other people seemed to mumble. Very few subjects reported difficulty hearing the telephone ringing or when following a conversation over the telephone. It seemed that when the sound source was close to the subjects' ears, they did not experience difficulty hearing, however when the sound source was further away, like the television or radio, approximately half of the subjects needed to turn up the volume.

It is interesting to note that although a high percentage of subjects were experiencing difficulty hearing in the presence of background noise, only a limited number of these subjects avoid social events where background noise is present. It seemed that difficulty with hearing did not necessary lead to the perception of a hearing handicap. Musiek et al. (1989) also found that 40 % of patients with normal puretone thresholds experienced difficulty with hearing in the presence of background noise while Rappaport et al. (1994) demonstrated an even lower percentage of only 25 %. However, during the current study hearing difficulties in the presence of background noise were reported in 73,33 % of the subjects in Group 1 and 70 % of the subjects in Group 2.

The discussion of the hearing difficulties and communication difficulties during every day life should be evaluated in the light of two additional findings obtained from the self-assessment questionnaire. These findings are illustrated in Table 4.2.

Table 4.2: Comparing hearing difficulties with other MS-related symptoms and the affect on quality of life

Additional findings	Number of subjects (percentage)	
	Group 1 = 15 subjects	Group 2 = 10 subjects
1. Difficulty with hearing affected quality of life	2 (13,33 %)	1 (10 %)
2. Rating hearing problems as compared to other MS-related problems:		
• One of the more significant problems of MS	0 (0 %)	1 (10 %)
• Equal to other MS related problems	1 (6,66 %)	0 (0 %)
• One of the less significant problems of MS	7 (46,66 %)	4 (40 %)
• Not applicable	7 (46,66 %)	5 (50 %)

Although most of the subjects experienced difficulty with hearing in scenarios depicted in items 1, 2 and 4 (Table 4.1), it is evident from Table 4.2 that their quality of life was not negatively affected. Klugman (2000) reported similar results. Since general, mental health and vitality plays a significant role in patients' quality of life (Rothwell et al., 1997), it is understandable that such a small percentage of subjects were of the opinion that their quality of life was affected by their hearing difficulties. Most of the subjects perceived their hearing difficulties as *less significant* when compared to other MS related problems. Hearing difficulties were rated as *not applicable* in 48 % of the cases due to the fact that a large percentage of the subjects were of the opinion that they had good hearing abilities. Klugman's (2000) patients also rated their hearing difficulties as insignificant when compared to other MS-related problems.

Descriptions of scenarios where subjects experienced difficulty with communication were obtained and enabled the researcher to develop a comprehensive understanding of their communicative competence during every day life. The inclusion of a questionnaire, in this case the COM-C (Schow et al., 1990) was useful, and should be included in the self-assessment questionnaire.

4.3 DESCRIPTION AND DISCUSSION OF RESULTS: SUB-AIM TWO

To determine the contribution of puretone audiometry, DPOAEs and CMs to the multiple test battery, in order to describe the degree of hearing impairment (as assessed by puretone audiometry), as well as the type of hearing impairment in terms of sensory involvement (as assessed by DPOAEs and CMs).

As stated in Chapter 3, puretone thresholds between 0 – 20 dB HL, over the frequency range 125 – 8 000 Hz were analysed as being within normal limits. A threshold/(s) worse than 20 dB HL at any given frequency was analysed as *abnormal* (Jerger & Jerger, 1980). None of the subjects displayed abnormal thresholds at only one test frequency, but rather at two or more frequencies. The DPOAEs were analysed as *abnormal* according to the preset Vanderbilt 65/55 Normative Range in the four octaves. The CM was analysed as either being *present* or *absent* when reversing the click polarity.

The following section will provide the results of the two groups. First the results of puretone audiometry, DPOAEs and the CM (as seen during the ABR recordings) of Group 1 will be provided.

4.3.1 Results of Group 1

Table 4.3: Results of puretone audiometry, DPOAEs and CMs of Group 1

Group1 (n=30 ears)	DPOAEs (625 - 7 625 Hz)		Octaves affected		Cochlear microphonic		Puretone thresholds (125 - 8 000 Hz)		Configurations (in case of abN puretone thresholds)	
Subject number	R	L	R	L	R	L	R	L	R	L
1	N	N	-	-	absent	present	abN	N	Dome-shaped	-
4	abN	abN	4-8 kHz	2-8 kHz	present	present	abN	abN	High-frequency	Sloping
5	N	abN	-	4-8 kHz	present	present	N	N	-	-
6	N	abN	-	4-8 kHz	present	present	abN	abN	High-frequency	High-frequency
8	N	N	-	-	present	present	abN	N	High-frequency	-
9	abN	abN	1-8 kHz	1-8 kHz	present	present	N	abN	-	Notch
11	abN	N	4-8 kHz	-	present	present	abN	N	Notch	-
15	N	N	-	-	absent	absent	N	N	-	-
16	abN	N	5-2 kHz	-	present	present	N	N	-	-
17	abN	abN	4-8 kHz	4-8 kHz	present	absent	abN	N	High-frequency	-
18	N	N	-	-	present	present	N	N	-	-
19	N	N	-	-	present	present	N	N	-	-
20	N	N	-	-	absent	absent	N	N	-	-
22	N	N	-	-	present	present	N	N	-	-
25	N	N	-	-	absent	absent	N	N	-	-
Total abN	10 ears (33,33 %)				8 ears (23,33 %)		9 ears (30 %)			

R = Right ear
L = Left ear
N = normal
abN = abnormal

Normal puretone thresholds across the frequency range (125 - 8 000Hz) were illustrated in 70 % of the ears. Eight subjects presented with bilateral normal puretone thresholds and 5 subjects had normal puretone thresholds in one ear. Verma and Lynn (1985) found 72,5 % of their patients with definite Multiple Sclerosis had normal puretone thresholds, which corresponds with the findings of the current study.

Nine ears (30 %) presented with thresholds outside normal limits. Two subjects had bilateral hearing losses and the remaining five presented with unilateral hearing losses. This finding of a higher prevalence of unilateral hearing losses corroborates with the literature, stating that unilateral hearing losses were most often found in patients with Multiple Sclerosis (Noffsinger et al., 1972; Citron et al., 1963; Dayal & Swisher, 1967; Luxon, 1980). The percentage of ears with abnormal puretone thresholds found in the current study corresponds with Dayal et al.'s (1966) study where 35 % of the ears displayed hearing impairment. Dayal and Swisher (1967) as well as Von Leden and Horton (1948) reported higher percentages of 59 % and 43 % of the ears with some degree of hearing impairment respectively, whereas Mustillo (1984) reported a much lower percentage of only 7 %.

Although other configurations were also present, those ears with hearing impairment most often displayed high-frequency hearing losses. Studies have shown a variety of audiometric configurations, including rising, high-frequency, dome-shaped and flat. Musiek et al. (1989) and Grénman (1985) also noted high-frequency losses to be the most common configuration found in patients with hearing losses. Stach et al. (1990) predicted that demyelinating lesions that encroach upon or occur at the root of the VIIIth nerve might cause high-frequency hearing loss in a way similar to the effects of cochlear nerve tumors.

The abovementioned results suggested that abnormal puretone thresholds were present, but only in a small percentage of ears. It is also suggested that the audiometric configuration was likely to be as variable as the site-of-lesion, and despite the fact that no single pattern adequately characterised the hearing impairment associated with MS, high-

frequency audiometric configurations were more apparent. It was predicted that high-frequency hearing losses could be the result of lesions upon or at the root of the VIIIth nerve.

When comparing the results of puretone audiometry with those of DPOAEs (across the frequency range of 625 – 7 625 Hz) and the CM, the following trends were present:

- **Normal puretone thresholds and DPOAEs**

  Seventeen (56.66 %) ears presented with normal puretone thresholds as well as normal DPOAEs. The presence of normal DPOAEs indicates that the preneural cochlear receptor mechanism was able to respond to sound in a normal fashion. However, six ears demonstrated absent CMs, which could have been the result of inner hair cell damage. Thus only eleven ears displayed no cochlear or sensory involvement.

- **Normal puretone thresholds with abnormal DPOAEs**

  Four ears presented with abnormal DPOAEs despite normal puretone thresholds. This finding may indicate subtle cochlear involvement that is not detected by the less sensitive audiogram (Hall, 2000). However, three of these ears had measurable CMs, which did not correlate with abnormal DPOAEs. The CM may be recorded in the absence of DPOAEs if receptor potentials remained intact, yet the complex mechanisms involved in active processing (motility) were disrupted (Hall, 2000). This can indicate that the inner hair cells of the cochlea were probably intact. Although hearing sensitivity was described as being normal if thresholds were in the 0 – 20 dB HL range, DPOAEs are likely to be abnormal if the hearing loss exceeds 15 dB HL (Hall, 2000). Parving et al. (1981) illustrated cochlear involvement in patients with definite Multiple Sclerosis displaying normal to near-normal audiometric thresholds using EcochG measurements. The finding of cochlear involvement in the presence of normal puretone thresholds have been illustrated by Parving et al. (1981) and also in the current study.

- **Abnormal puretone thresholds with abnormal DPOAEs**

  Six ears presented with abnormal puretone thresholds as well as abnormal DPOAEs. It can be concluded that this indicated outer hair cell damage resulting in cochlear hearing losses since no middle ear involvement was detected using either puretone thresholds and/or tympanometry. However, all of these ears presented with CMs, which can be recorded in the absence of DPOAEs. Withnell (2001) also found the CM to be present in ears with outer hair cell pathology and stated that the presence of a CM in the absence of an otoacoustic emission should not be construed as indicative of normal outer hair cell function.

- **Abnormal puretone thresholds with normal DPOAEs**

  Three subjects displayed abnormal puretone thresholds in the right ear despite normal DPOAEs in those ears. In two of these ears the CM was present. Hall (2000) provided a possible explanation for the finding of abnormal puretone thresholds with normal DPOAEs. If the DPOAE amplitudes are entirely normal despite hearing thresholds exceeding 15 dB HL, one must suspect either invalid puretone findings or, far less likely, neural (retrocochlear) auditory dysfunction. The researcher can confirm reliable puretone findings. The fact that MS is a disease affecting the CNS and that the CM was present may suggest retrocochlear auditory involvement.

During a further analysis of the abovementioned results, the DPgram was compared with the configuration of the affected audiograms. This was possible due to the fact that the frequency of the DPOAE stimulus was aligned with the audiometric frequency and the DPOAE reflects the integrity of the cochlea at the f_2 frequency (Hall, 2000). The following results were obtained. As seen in Table 4.3, the high-frequency configurations corresponded with the DPgrams in the following manner:

- three ears presented with abnormal DPgrams in the corresponding high-frequency octave (4-8 kHz), and the remaining two ears had normal DPgrams in this octave. However these puretone thresholds were not worse than 30 dB HL at either 6 000 or 8 000 Hz);

- two audiograms with notch configurations demonstrated corresponding DPgrams;
- one ear's audiogram with a sloping configuration, also displayed abnormal DPgrams in octaves 2 - 4 and 4 - 8 kHz; and
- one ear's audiogram with a dome-shaped configuration (puretone thresholds were not worse than 25 dB HL or 30 dB HL in the low and high frequencies respectively) also displayed normal DPgrams. These puretone thresholds could however still produce normal DPgrams (Hall, 2000).

A large percentage of subjects presented with normal puretone thresholds, DPOAEs and present CMs indicating that no sensory involvement was present. The DPgrams imitated the audiometric configurations of the affected audiograms in most cases.

The following section will describe the results of puretone audiometry, DPOAEs as well as the CM (as seen during ABR recordings) of Group 2.

4.3.2 Results of Group 2

Table 4.4: Results of puretone audiometry, DPOAEs and CMs of Group 2

Group2 (n=20 ears)	DPOAEs (625 - 7 625 Hz)		Octaves affected		Cochlear microphonic		Puretone thresholds (125 - 8 000 Hz)		Configurations (in case of abN puretone thresholds)	
Subject number	R	L	R	L	R	L	R	L	R	L
2	N	abN	-	4-8 kHz	present	absent	abN	abN	High-frequency	High-frequency
3	abN	abN	4-8 kHz	4-8 kHz	present	absent	N	abN	-	Notch
7	N	N	-	-	present	present	N	abN	-	High-frequency
12	abN	abN	2-8 kHz	1-4 kHz	present	present	abN	abN	High-frequency	Other
13	abN	abN	4-8 kHz	4-8 kHz	present	present	abN	abN	High-frequency	High-frequency
14	abN	abN	4-8 kHz	4-8 kHz	absent	absent	abN	abN	High-frequency	Dome-shaped
21	abN	abN	1-8 kHz	1-8 kHz	present	present	N	abN	-	Rising
23	N	N	-	-	present	absent	N	N	-	-
24	abN	abN	1-2 kHz 4-8 kHz	1-8 kHz	present	absent	abN	abN	High-frequency	High-frequency
26	abN	abN	4-8 kHz	4-8 kHz	present	present	abN	abN	High-frequency	High-frequency
Total abN	**15 ears (75 %)**				**6 ears (30 %)**		**15 ears (75 %)**			

R = Right ear
L = Left ear
N = normal
abN = abnormal

Due to the fact that the subjects of this group were exposed to single episodes (for example subjects no. 7, 12, 13, 14, 21 & 26) or continuous levels of noise (for example subjects no. 2, 3, 23 & 24), the following findings were probably the result of two pathologies: (1) cochlear pathology due to noise exposure and/or (2) brainstem pathology due to MS. Thus the following results of Group 2 may not be exclusively related to MS:

- More ears presented with impaired puretone thresholds than Group 1.
- More bilateral than unilateral hearing losses were found.
- The affected audiograms consisted of high-frequency configurations (55 %), characterised by a gradual slope at 6 and 8 kHz and/or 4 kHz. Other audiometric configurations, such as notch, rising, dome-shaped and *other* were observed to a limited extend. Despite this group's history of noise exposure the characteristic notch configuration was only observed in one ear. However, if subjects were exposed to noise over several years, the notch can be expected to widen and all the high frequencies will subsequently be affected (Jorden & Roland, 2000). According to Ginsberg and White (1994) the threshold at 4 000 Hz will deteriorate as the damage extends to other high frequencies. This was not observed in these audiograms during the current study, as the thresholds were mostly affected at 8 000 Hz and not at 4 000 Hz. Whether these high-frequency configurations could be solely attributed to noise-induced hearing losses remains uncertain, since MS can also affect the puretone thresholds in the high frequencies (Stach et al., 1990). Furthermore, high-frequency configurations are most often present in presbycusis, which can't be excluded as a possible cause as subject's ages ranged from 20 to 50 years and presbycusis can occur from as early as 40 years (Brant & Fozard, 1990).

A high percentage of subjects presented with abnormal high-frequency puretone audiograms. As discussed this finding cannot be contributed to MS exclusively, since noise-induced hearing losses and presbycusis cannot be excluded.

When comparing the results of puretone audiometry with those of DPOAEs (across the frequency range of 625 - 7 625 Hz) and the CM, the following trends were present:

- **Normal puretone thresholds and DPOAEs**

  Although most of the ears in Group 2 displayed outer hair cell damage in the cochlea, there were three ears, that presented with both normal puretone thresholds and DPOAEs across all frequencies tested. Two of the three ears showed evidence of present CMs, and normal hearing sensitivity was found.

- **Normal puretone thresholds with abnormal DPOAEs**

  Abnormal DPOAEs were present in two ears that displayed both normal puretone thresholds and present CMs, which again proves that DPOAEs are sensitive in the detection of outer hair cell damage before it is visible on the audiogram. Hall (2000) described reduced DPOAE amplitudes even though the audiogram was still within the normal clinical region in patients with a history of exposure to high levels of noise. The presence of the CM in the absence of the DPOAEs can possibly be indicative of normal inner hair cell function.

- **Abnormal puretone thresholds with abnormal DPOAEs**

  Thirteen ears (65 %) with abnormal puretone thresholds also presented with abnormal DPOAEs. This is indicative of outer hair cell damage resulting in affected thresholds. Only five of these ears had absent CMs and the remaining eight ears showed evidence of present CMs. These results proved that the CM could be present in the absence of DPOAEs, which corresponded with Hall's (2000) findings.

- **Abnormal puretone thresholds with normal DPOAEs**

  An additional two ears' DPOAEs were interpreted as *normal* (only one DP point in the octave was affected). After closer examination the amplitude of the DP frequency 7 625 Hz was abnormal, which corresponds well with impaired hearing

sensitivity at 6 000 and 8 000 Hz. These two ears presented with very high-frequency cochlear damage, and thus sensory involvement.

The DPOAE amplitudes were plotted as a function of f_2 and are expected to agree with the audiogram (Hall, 2000). Due to DPOAEs being frequency specific, the configurations of the DPgrams were compared to the puretone audiograms. The following results were found:

- In those ears displaying high-frequency hearing losses, the audiogram corresponded with the abnormal DPgrams found in the high frequency octave. Six ears with high-frequency hearing losses also presented with abnormal DPgrams in the high-frequency octave (4 - 8 kHz). Of the remaining five ears, two presented with abnormal DPgrams in octaves 1 - 2, 2 - 4 and 4 - 8 kHz, and another one with abnormal DPgrams in octaves 2 - 4 and 4 - 8 kHz. The remaining two ears had normal DPgrams.
- The audiogram of the ear with a rising configuration did not correspond with the abnormal DPgrams found at octaves 1 - 2 and 4 - 8 kHz.
- The audiogram of the ear with a dome-shaped configuration partially corresponded with abnormal DPgrams found in octave 4 - 8 kHz.
- One ears' audiogram could not be categorised and was described under the *other* configuration. The abnormal DPgram in octaves 1 - 2 and 2 - 4 kHz imitated the audiometric configuration.

A large number of the subjects displayed abnormal puretone thresholds as well as abnormal DPOAEs, indicating cochlear involvement. Once again most of the DPgrams correlated with the audiometric configurations of the affected audiograms.

The inclusion of puretone audiometry contributed information regarding the degree of hearing impairment and the configurations of affected audiograms. Puretone audiometry remains the foundation of every audiometric test battery, but should not be used in isolation during the assessment of patients with Multiple Sclerosis.

In addition the inclusion of DPOAEs enabled the researcher to objectively assess those ears displaying normal and abnormal puretone thresholds, to determine whether sensory and/or cochlear involvement was present. DPOAEs proved to be a useful tool in identifying those subjects who presented with definite cochlear or early cochlear damage.

The measurement of an absent CM in the presence of abnormal DPOAEs contributed to the confirmation of cochlear involvement. However, a present CM in the presence of abnormal DPOAEs was possibly the result of normal inner hair cell function. Furthermore an absent CM in the presence of normal DPOAEs can possibly be the result of inner hair cell damage and/or impaired synaptic transmission of the inner hair cells to the dendrites of the auditory nerve fibres (Withnell, 2001). Thus the CM provided more detailed information regarding the cochlear function of subjects with Multiple Sclerosis.

4.3.3 Summary of results obtained from both groups

The following observations were made when reviewing the results of both groups for sub-aim two:

- **Degree of hearing loss**

  Although not calculated, it was evident that most of the hearing losses were of a mild degree (20 – 40 dB HL), very few of a moderate degree (55 – 70 dB HL) and only one ear presented with a puretone threshold of 75 dB HL at 6 000 Hz (severe hearing loss at one frequency). Some investigators generally agreed that when loss of hearing sensitivity exists, it is of a mild degree and less than 35 dB HL (Luxon, 1980; Noffsinger et al., 1972). In fact, profound hearing losses appear not to be typical in most patients suffering from Multiple Sclerosis (Daugherty et al., 1983).

❖ **Configuration of affected audiograms**

The following configurations were observed in the 48 % of ears with abnormal puretone thresholds:

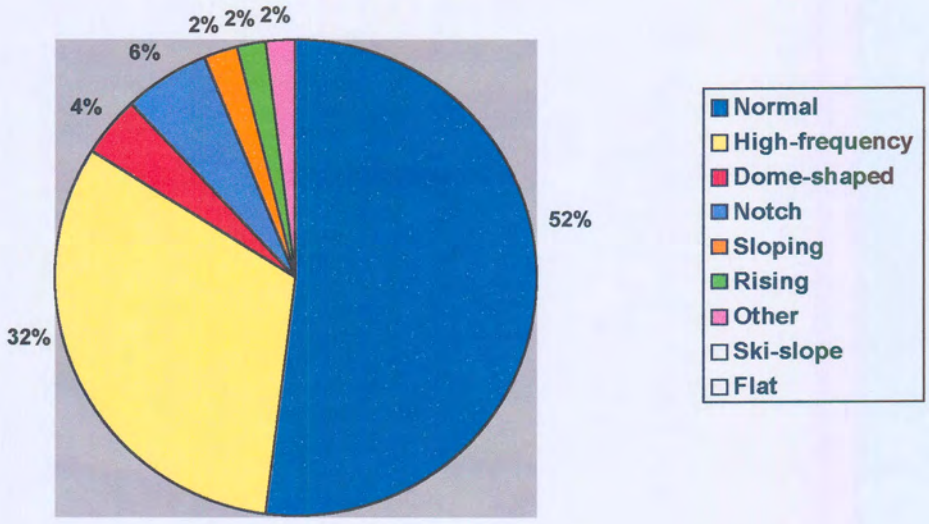


Figure 4.3: Configuration of audiograms

Slightly more than half of the subjects demonstrated normal puretone audiograms, with high-frequency hearing losses being the most frequent configuration present.

❖ **Puretone audiometry and DPOAEs**

The results of puretone audiometry in conjuction with DPOAEs were as follows:

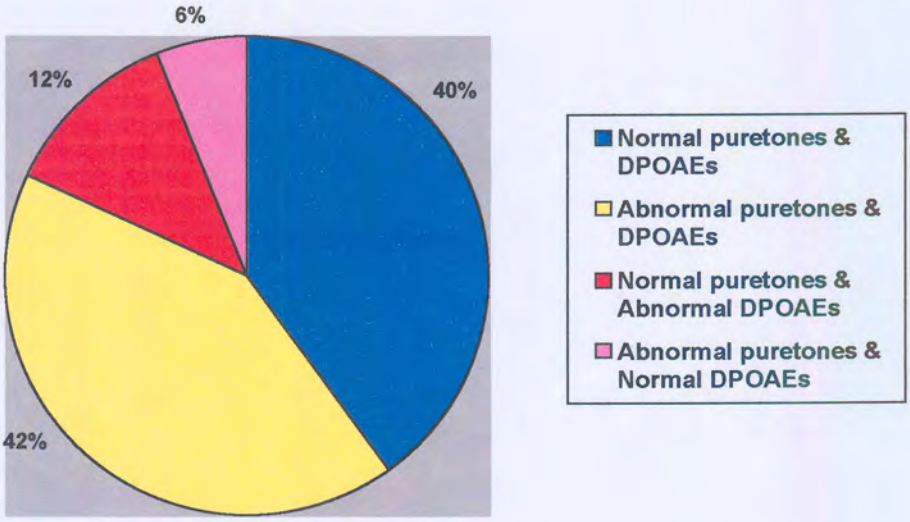


Figure 4.4: Results of puretone audiometry and DPOAEs

- No ears presented with abnormal DPOAEs in all four octaves (outcome 2).
- Thirteen ears (26 %) displayed normal puretone thresholds, normal DPOAEs as well as observable CMs indicating normal hair cell function, and thus no sensory involvement. Twenty ears (40 %) presented with normal puretone thresholds and normal DPOAEs indicating normal outer hair cell function. As expected 32 % and 6 % of these ears belonged to Group 1 and 2 respectively.
- Twenty-one ears (42 %) presented with abnormal puretone thresholds with corresponding abnormal DPOAEs in the same ear, of which 12 % and 30 % belonged to Group 1 and 2 respectively. Only five of these ears had absent CMs and the results were indicative of definite outer hair cell involvement.
- The remaining 18 % of the ears displayed either abnormal puretone thresholds or abnormal DPOAEs. Twelve percent of these ears demonstrated subtle cochlear involvement without affecting thresholds beyond 20 dB HL. Only 6 % of the ears presented with abnormal puretone thresholds and normal DPOAEs possibly indicating retrocochlear involvement.

4.4 DESCRIPTION AND DISCUSSION OF RESULTS: SUB-AIM THREE

To determine the contribution of ABRs in subjects with Multiple Sclerosis using both R and C click polarities consecutively.

The criteria, possible reasons and examples for ABR abnormality were outlined in Chapter 3, Table 3.12. A comparison between the two groups and the two polarities will be provided.

4.4.1 Presence of ABR waves

Table 4.5: Distribution of absent and doubtful waves according to both click polarities for both groups

Polarity	Group 1 (n=30 ears)		Group2 (n=20 ears)	
	R	C	R	C
Absence of:				
Wave I (alone)	-	-	-	1 ear
	1 ear doubtful*	1 ear doubtful	-	1 ear doubtful
Wave III (alone)	1 ear	3 ears	-	-
	-	2 ears doubtful	-	1 ear doubtful
Wave V (alone)	-	1 ear	-	-
	3 ears doubtful	2 ears doubtful	4 ears doubtful	1 ear doubtful
Waves III & V	1 ear	1ear	-	-
	1 ear doubtful	-	-	-
Waves I & V	-	-	-	-
	-	-	1 ear doubtful	-
Waves I & III	-	-	-	-
	-	-	2 ears doubtful	-
Waves I, III & V	-	-	1 ear	-
	-	-	-	-
TOTAL	**7 ears (23,33 %)**	**10 ears (33,33 %)**	**8 ears (40 %)**	**4 ears (20 %)**

R = Rarefaction click polarity
C = Condensation click polarity

*Poor morphology and reduced amplitudes necessitated that the presence of some waves had to be analysed as doubtful.

Most of the ears in both groups displayed waves that could be described as *present*. Ears belonging to Group 2 illustrated a higher percentage of *absent* and *doubtful* waves using the R, compared to the C click polarity.

In both groups the most frequent abnormality observed was an ***absent or doubtful Wave V, with the preservation of earlier waves*** using the R or C click polarity. The absence of Wave V with the preservation of earlier waves has not been associated with high-frequency cochlear hearing losses in the literature (Hood, 1998; Hall & Mueller 1997). This finding, especially in Group 2, could not been the result of noise-induced hearing loss. According to the literature, an absent Wave V with the preservation of earlier waves was the most common abnormality in patients with Multiple Sclerosis (Jerger et al., 1986; Chiappa, 1990). The presumed generators of Wave V are the lateral lemniscus as the auditory nerve enters the inferior colliculus (Hall & Mueller, 1997). The presence of lesions at these locations and even rostral to the lesions can eliminate Wave V (Arnold, 2000).

Thereafter, especially the ears of Group 1 demonstrated an ***absent or doubtful Wave III with the preservation of Waves I and V***. The presumed anatomic generators of Wave III are structures such as the trapezoid body and superior olivary complex within the auditory pathways of the pons (Hall & Mueller, 1997). According to Hall and Mueller (1997) Wave III is absent either due to a hearing loss or brainstem dysfunction. Since most of the ears belonging to Group 1 presented with normal hearing sensitivity, a brainstem dysfunction is most probably the cause of this finding.

Absent and doubtful Waves III and V with the preservation of Wave I, were found in only three ears. This indicates auditory involvement of the acoustic nerve, or at least to the proximal part of it, seeing as Wave I is generated by the distal part of the acoustic nerve (Hall & Mueller, 1997). The low percentage of ears presenting with absent waves after Wave I did not correlate with Jerger et al.'s (1986) findings, where a higher percentage of ears presented with a loss of all waves after Wave I. However, this finding was clinically valuable in the current study and can be associated with MS.

Although high-frequency cochlear hearing losses could result in a small or absent Wave I (Hall & Mueller, 1997), a similar number of ears with an absent and doubtful Wave I were found between the two groups. Other possible explanations for this abnormality could be related to the following:

- The high-pass filter of 300 Hz could have resulted in a small or absent Wave I due to an increase in filter distortion resulting in wave alterations (Hall & Mueller, 1997). This filter setting was selected due to the high amount of artifacts found during the preliminary study.
- Although the absence of Wave I was previously reported in patients with Multiple Sclerosis (Chiappa et al., 1980; Daugherty et al., 1983; Russolo & Poli, 1983; Verma & Lynn, 1985) this abnormality is uncommon, ranging from 2 – 10 % of patients (Bergamaschi et al., 1997). Evidence has linked segmental demyelination and abnormal refractory periods to the peripheral nerves of patients with Multiple Sclerosis (Hopf & Eysholdt, 1978).

The researcher endorsed the possibility that the effects of the central demyelinating process extend distally, involving the peripheral myelin of the VIIIth nerve based on the absence of Wave I (Verma & Lynn, 1985). These results support the contention that peripheral nerve involvement may occur concomitantly with central lesions and the ABR was capable of detecting these subclinical lesions (Jacobson & Jacobson, 1990).

The percentages of both groups using both click polarities were combined. ABR abnormality was present in 29 % of the ears during the analysis of the *presence* of waves and should therefore be included as one of the criteria to determine ABR abnormality.

4.4.2 Repeatability of ABR waves

Due the fact that the judgment of repeatability is subjective in nature, repeatability was defined as waveforms being reproduced with at least two repetitions of recordings performed using identical stimulus and acquisition parameters (Arnold, 2000). The presentation of the R and C click polarities consecutively revealed the following abnormalities in the two groups.

Table 4.6: Distribution of waves with poor repeatability according to both click polarities for both groups

Polarity	Group 1 (n=30 ears)		Group 2 (n=20 ears)	
	R	C	R	C
Poor repeatability of:				
Wave I (alone)	1/30 (3,3 %)	-	2/20 (10 %)	1/18 (5,5 %)
Wave III (alone)	1/28 (3,5 %)	2/26 (7,6 %)	-	1/19 (5,2 %)
Wave V (alone)	3/29 (10,3 %)	2/28 (7,1 %)	4/20 (20 %)	-
TOTAL	**5 ears (5,74 %)**	**4 ears (7,4 %)**	**6 ears (15 %)**	**2 ears (5,4 %)**

R = Rarefaction click polarity
C = Condensation click polarity

Most of the ears in both groups demonstrated repeatable waves. Poor repeatability of Wave V when using the R click polarity compared to the C click polarity seemed to be the most frequent abnormality observed. The percentage of waves with poor repeatability in the current study was lower than those reported in the literature. Poor waveform morphology and trace repeatability are common findings in patients with Multiple Sclerosis. Desynchronisation of neural impulses produced by conduction abnormalities associated with MS, are thought to be the major cause of poor ABR waveform response stability (Drulovic et al., 1993). Repeatability of waves is not dependent on the type of click polarity used, but presumably due to desynchronisation resulting from neural plaque formation (Prasher & Gibson, 1980; Robinson & Rudge, 1980; Jacobson & Jacobson, 1990). However a high number of abnormalities, regarding the repeatability of waves, were not present despite using both click polarities.

4.4.3 Absolute latency (AL) of ABR waves

The AL was calculated for waves analysed as being either *present* or *doubtful*. Despite the poor repeatability of waves found in 11 ears (using the R click polarity) and 6 ears (using the C click polarity) in the two groups, the AL of these waves was still calculated. The AL of certain waves could be not be analysed using either the R or C click polarity due to the:

- Absence of Wave I in two ears using the C click polarity;
- Absence of Wave III in two ears (R click polarity) and in five ears (C click polarity); and
- Absence of Wave V in one ear (R click polarity) and in three ears (C click polarity).

Table 4.7: Distribution of waves with abnormal absolute latency according to both click polarities for both groups

Polarity	Group 1 (n=30 ears)		Group 2 (n=20 ears)	
	R	C	R	C
Prolonged absolute latency of:				
Wave I (alone)	-	-	-	-
Wave III (alone)	1/28 (3,6 %)	1/26 (3,8 %)	2/20 (10 %)	1/19 (5,2 %)
Wave V (alone)	1/29 (3,4 %)	-	-	-
TOTAL	**2 ears (3,5 %)**	**1 ear (3,8 %)**	**2 ears (10 %)**	**1 ear (5,2 %)**

R = Rarefaction click polarity
C = Condensation click polarity

Most of the ears displayed waves with normal AL using either the R or C click polarity. ***Prolonged latency of Wave III*** was the most frequent abnormality in both groups. The percentages found in the current study were much lower than those in the literature. Musiek et al. (1989) reported 35 % of 52 ears with abnormal Wave III latencies using the

R click polarity. Hannley et al. (1983) also found a high percentage of ears with delayed Wave III and V latencies in patients with confirmed Multiple Sclerosis and other investigators such as Robinson and Rudge (1975), Robinson and Rudge (1977), Stockard et al. (1977) and Thorton et al. (1978) reported a delayed Wave V as the predominant feature.

4.4.4 Interpeak latency (IPL) of ABR waves

The IPL of the following waves could not be analysed using either the R or C click polarities, due to *absent* waves:

- Wave I-III and III-V in two ears (R click polarity) and in six ears (C click polarity); and
- Wave I-V in one ear (R click polarity) and in four ears (C click polarity);

Table 4.8: Distribution of waves with abnormal interpeak latency according to both click polarities for both groups

Polarity	Group 1 (n=30 ears)		Group 2 (n=20 ears)	
	R	C	R	C
Prolonged interpeak latency of:				
Wave I – III	1/28 (3,5 %)	-	1/20 (5 %)	1/18 (5,2 %)
Wave III – V	1/28 (3,5 %)	5/25 (20 %)	1/20 (5 %)	3/19 (15,7 %)
Wave I -V	1/29 (3,4 %)	2/28 (7,1 %)	1/20 (5 %)	1/18 (5,5 %)
TOTAL	**3 ears (3,5 %)**	**7 ears (13,2 %)**	**3 ears (5 %)**	**5 ears (9 %)**

R = Rarefaction click polarity
C = Condensation click polarity

The analysis of IPL did not yield clinically significant results, as most of the ears in both groups demonstrated normal IPL using either the R or C click polarity. When comparing the number of abnormalities using both polarities, a larger percentage of ears demonstrated abnormal IPL using the C click polarity. The ***Wave III-V interval prolongation*** (especially after the presentation of the C click polarity) was most often observed. This correlated with findings of Chiappa (1990); Lynn et al. (1980); Shanon et al. (1981) and Hammond et al. (1986), where the Wave III-V interval was most often affected. However, some investigators reported conflicting findings. Shanon et al. (1981) and Hannley et al. (1983) found the Wave I-III interval to be more frequently affected than the Wave III-V interval. Abnormal Wave I-V intervals were reported in a small percentage of patients by Chiappa et al. (1980), which correlates with the current study's findings. Abnormal IPL can indicate a deficit in the conduction of neural impulses from the various generators of the auditory brainstem (Drulovic et al., 1993), due to demyelinated areas.

4.4.5 Interaural Wave V latency difference (ILD)

The ILD could not be analysed when Wave V was absent in one or both ears. The results will be provided according to the number of subjects, as this is an interaural measurement between two ears. The ILD of both groups could not be measured in:

- three subjects (C click polarity); and
- one subject (R click polarity).

Table 4.9: Distribution of subjects with abnormal interaural latency difference of Wave V according to both click polarities for both groups

Polarity	Group 1 (n=30 ears)		Group 2 (n=20 ears)	
	R	C	R	C
Abnormal ILD of Wave V	4/14 (28,6 %)	3/13 (23 %)	3/10 (30 %)	2/9 (22,22 %)

R = Rarefaction click polarity
C = Condensation click polarity

The ILD of Wave V was abnormal in a relatively high percentage (26 %) of subjects, using both click polarities. The percentage of subjects displaying abnormal ILD of Wave V was similar for both groups. A slightly increased number of subjects illustrated abnormal ILD of Wave V using the R click polarity compared to the C click polarity. The findings of the current study correlated with the 33 % of patients who demonstrated abnormal ILD of Wave V, using the R click polarity, during a study performed by Jerger et al. (1986).

The researcher agrees with Arnold's (2000) statement that the ILD of Wave V in the general population may be a more sensitive measure than the AL of Wave V, due to the fact that Wave V can be prolonged in one ear relative to the other (but still be outside the normal range). False positive results could be obtained when a unilateral or asymmetrical hearing loss is present. The Wave V AL may be significantly prolonged in one ear simply due to the hearing loss and not as a result of retrocochlear pathology (Arnold, 2000). Owing to the fact that a multiple battery of test procedures was used in the current study, the presence of false positive results was unlikely. Despite the fact that four subjects with abnormal ILD of Wave V also displayed asymmetrical hearing losses (of which two had bilateral abnormal DPOAEs), the Wave V AL was not significantly prolonged. Only one subject presented with prolonged Wave V AL in one ear even though the puretone thresholds were within normal limits bilaterally.

The ILD is highly sensitive and specific for VIIIth nerve tumor detection, however the literature is scarce on the effect that brainstem lesions (as caused in MS) have on the ILD of Wave V (Musiek et al., 1994). According to Musiek et al. (1989) the sensitivity of ILD of Wave V measured in patients with Multiple Sclerosis is lower than is seen in patients with VIIIth nerve tumors. Brainstem lesions may affect both ipsilateral and contralateral brainstem auditory pathways, causing similar latency delays of Wave V for each ear. The fact that the ILD of Wave V was the only abnormal ABR measure in 4 subjects (using either the R or C click polarity) makes this measure sensitive in detecting brainstem lesions.

The amplitude ratios of Wave V/I were measured and will be discussed in the following section.

4.4.6 Wave V/I amplitude ratio

The Wave V/I amplitude ratios could not be measured due to the absence of Wave I and/or V in:

- one ear (R click polarity); and
- four ears (C click polarity).

When the presence of Waves I and V was described as *doubtful*, these waves were still included during the analysis of amplitude ratios.

Table 4.10: Distribution of abnormal amplitude ratios of Wave V/I according to both click polarities for both groups

Polarity	Group 1 (n=30 ears)		Group 2 (n=20 ears)	
	R	C	R	C
Amplitude ratio of Wave V/I	9/29 (31 %)	11/28 (39,28 %)	7/20 (35 %)	12/18 (66,66 %)

R = Rarefaction click polarity
C = Condensation click polarity

In determining abnormal ABRs, the ***amplitude ratio of Wave V/I*** yielded the highest percentage of abnormality in both groups, using either the R or C click polarity, to such an extent that in 15 ears (7 ears in Group 1 and 8 ears in Group 2) the amplitude ratio of Wave V/I was the only abnormal ABR parameter. The amplitude of Wave V was more reduced than that the amplitude of Wave I. Reduced amplitudes of later ABR waves have been reported in other ABR studies (Chiappa et al., 1980; Robinson & Rudge, 1975). No abnormally increased Wave I amplitudes were recorded in the current study. The following explanations for these findings were supplied in the literature:

- Reduced Wave V amplitudes could be the result of poor temporal synchrony of the auditory nerve (Starr et al., 2001) possibly due to incomplete myelination of nerve fibres, which is common in patients with Multiple Sclerosis (Elidan et al. 1982).
- Starr and Achor (1975); Hall and Mueller (1997) stated that the amplitude of later ABR waves are highly sensitive to brainstem pathology, which resulted in reduced amplitudes. This finding was substantiated by Arnold (2000).
- Musiek et al. (1989) stated that the presumed brainstem generators of Wave V are more likely to be affected in patients with Multiple Sclerosis than those of Wave I (cochlear nerve).
- According to Hall and Mueller (1997) a Wave I with reduced amplitude could be present in high-frequency cochlear hearing losses. High-frequency cochlear hearing losses were identified in the current study, which could have contributed to abnormal Wave V/I amplitude ratios. This could account for the higher percentage of abnormal amplitude ratios that were present in ears belonging to Group 2.

In both groups the C click polarity yielded the highest percentage of abnormality. This could not be related to the specific click polarity since Hughes et al. (1981); Sand and Sulg (1984) did not find significant differences between the amplitude ratios of Wave V/I when using different click polarities. A possible explanation for this finding can be related to auditory nerve fatigue, since the C click polarity was always presented after the recording of ABRs using the R click polarity.

4.4.7 Discrepancies and similarities of different types of ABR abnormalities when reversing the click polarity

ABR recordings were elicited after the presentation of the R and C click polarities and interesting findings were observed in some of the subjects. Discrepancies in ABR abnormalities were present, even in the same ear, when reversing the click polarity. Maurer (1985) also described these discrepancies as dependent on the phase of the stimulus.

More specifically, Wave III was absent using one click polarity and present using the reverse polarity in the same ear (under the same recording conditions). This phenomenon is not present in persons with normal hearing sensitivity or in patients with other peripheral hearing disorders (Chiappa, 1990). These findings can have diagnostic implications for the recording and analysis of ABRs in patients with Multiple Sclerosis.

The following section will describe the discrepancies and similarities of different types of ABR abnormalities demonstrated in some subjects, as observed during the presentation of both the R and C click polarity.

Table 4.11: The presence and absence of waves when reversing the click polarity

Subject number	Right ear	R	C	Left ear	R	C
Group 1						
1	Discrepancy	Present V	Doubtful V	Discrepancy	Present III	Doubtful III
5	Discrepancy	Doubtful III	Absent III	Similarity	Doubtful V	Doubtful V
	Discrepancy	Doubtful V	Absent V	-	-	-
8	-	-	-	Discrepancy	Doubtful V	Absent V
9	Discrepancy	Present V	Doubtful I	Discrepancy	Present III	Douibtful III
22	-	-	-	Discrepancy	Present III	Absent III
25	Similarity	Absent III	Absent III	Similarity	Absent III	Absent III
	-	-	-	Discrepancy	Absent V	Present V
Group 2						
3	-	-	-	Discrepancy	Present I	Absent I
21	Discrepancy	Present I	Absent I	-	-	-
	Discrepancy	Present III	Absent III	-	-	-
	Discrepancy	Present V	Absent V	-	-	-

R = Rarefaction click polarity
C = Condensation click polarity

As illustrated, 10 ears presented with discrepancies of ABR abnormalities indicating that an ear displayed present waves in the one phase and absent waves in the other phase.

Similar results were reported by Maurer (1985) and Emerson et al. (1982). Emerson et al. (1982 did not observe a polarity-dependent disappearance of Wave V in normal hearing subjects, and concluded that either an abnormality or an infrequently occurring normal variant was the cause.

Only subject no. 25 demonstrated an absent Wave III in both ears using both click polarities, although Wave V was absent in the left ear when using the R click polarity and present when using the C click polarity. In subject no. 5 the left ear presented with a doubtful Wave V using both click polarities.

Table 4.12: Repeatability of waves when reversing the click polarity

Subject number	Right ear	R	C	Left ear	R	C
Group 1						
1	Discrepancy	Repeatable V	Poor V	Discrepancy	Repeatable III	Poor III
5	Discrepancy	Poor III	Absent III	Similarity	Poor V	Poor V
	Discrepancy	Poor V	Absent V	-	-	-
6	Discrepancy	Poor I	Repeatable I	-	-	-
9	-	-	-	Discrepancy	Repeatable III	Poor III
25	Discrepancy	Poor V	Repeatable V	-	-	-
Group 2						
12	Discrepancy	Repeatable III	Poor III	-	-	-
	Discrepancy	Poor I	Repeatable I	-	-	-
13	Discrepancy	Poor V	Repeatable V	Discrepancy	Poor V	Repeatable V
14	Discrepancy	Poor V	Repeatable V	Discrepancy	Poor V	Repeatable V
	-	-	-	Discrepancy	Poor I	Repeatable I
26	Discrepancy	Repeatable I	Poor I	-	-	-

R = Rarefaction click polarity
C = Condensation click polarity

Discrepancies in ABR abnormalities were found in 12 ears. This indicated poor repeatability of some waves when using one click polarity, and not when using the other click polarity. Only subject no. 5 demonstrated poor repeatability of Wave V in the left ear when using both click polarities.

Table 4.13: Absolute latency of waves when reversing the click polarity

Subject number	Right ear	R	C	Left ear	R	C
Group 1						
1	-	-	-	Discrepancy	Normal III	Prolonged III
5	-	-	-	Discrepancy	Prolonged V	Normal V
8	Discrepancy	Prolonged III	Normal III	-	-	-
Group 2						
12	Similarity	Prolonged III	Prolonged III	-	-	-
14	Discrepancy	Prolonged III	Normal III	-	-	-

R = Rarefaction click polarity
C = Condensation click polarity

Four ears demonstrated normal AL using one phase and prolonged AL when using the other phase. Two ears displayed prolonged Wave III AL using the R click polarity compared to normal Wave III AL when using the C click polarity. Only one ear presented with prolonged AL of Wave III when using both click polarities.

According to Hood (1998) different click polarities yielded different AL of waves, for example:

- When using the R click polarity the AL of Wave I and III is decreased;
- The Wave I and III AL may be prolonged when using the C click polarity; but
- There is an insignificant difference in the Wave V AL using either the R or C click polarity for normal individuals (Hood, 1998).

A ± 2,5 SD from the mean was applied during the analysis of the AL and thus these decreased latencies (using the R click polarity) and prolonged latencies (using the C click polarity) could not have affected the high percentage of different ABR abnormalities found in the current study.

Table 4.14: Interpeak latency of waves when reversing the click polarity

Subject number	Right ear	R	C	Left ear	R	C
Group 1						
1	-	-	-	Discrepancy	Normal III-V	Prolonged III-V
4	-	-	-	Discrepancy	Normal III-V	Prolonged III-V
5	-	-	-	Similarity	Prolonged III-V	Prolonged III-V
	-	-	-	Discrepancy	Prolonged I-V	Normal I-V
8	Discrepancy	Prolonged I-III	Normal I-III	-	-	-
9	-	-	-	Discrepancy	Normal III-V	Prolonged III-V
	-	-	-	Discrepancy	Normal I-V	Prolonged I-V
19	Discrepancy	Normal III-V	Prolonged III-V	Discrepancy	Normal III-V	Prolonged III-V
	Discrepancy	Normal I-V	Prolonged I-V	-	-	-
Group 2						
2	-	-	-	Discrepancy	Prolonged III-V	Normal III-V
7	Discrepancy	Normal III-V	Prolonged III-V	-	-	-
	Discrepancy	Normal I-V	Prolonged I-V	-	-	-
13	Discrepancy	Prolonged I-III	Normal I-III	-	-	-
	Dsicrepancy	Prolonged I-V	Normal I-V	-	-	-
23	Discrepancy	Prolonged III	Prolonged III-V	Discrepancy	Normal III-V	Prolonged III-V

R = Rarefaction click polarity
C = Condensation click polarity

Subjects no. 7, 9 and 19 displayed prolonged IPL of Wave III-V and I-V when using the C click polarity, but normal IPL of these waves when using the R click polarity (in the same ear). Subject no. 13 demonstrated prolonged IPL of Wave I-III and Wave I-V when using the R click polarity, with normal IPL of these waves when using the C click polarity.

According to Hammond et al. (1986) significant differences of the IPL in control groups, in relation to either click polarity or gender, were not present. However, during the recording and analysis of IPL of the current study, 12 ears presented with discrepancies after reversing the click polarity. Only subject no. 5 demonstrated prolonged Wave III-V IPL in the left ear when using both polarities.

The literature suggests that identical abnormalities should occur in both ears, despite the type of click polarity used (Hammond et al., 1986). Maurer (1985) found identical patterns of abnormality in 30 % of ears, but only 4 ears (8 %) displayed identical ABR abnormalities in the current study when using the two click polarities.

The cases in which ABR recordings were normal using one click polarity and abnormal when using the reverse polarity, are of particular clinical interest. Whether these ABR recordings should be regarded as abnormal remains disputed. Hammond et al. (1986) claimed that this constitutes abnormality, since the absence of similar occurrences was not reported in control groups. It was also suggested that all patients should be evaluated using both click polarities consecutively. Sand (1991b) was of the opinion the ABR recordings with R versus C discrepancies should be interpreted with more caution as opposed to those responses where similarity was observed, at least until results from longitudinal studies are available.

Two explanations were provided, by several researchers for these discrepancies between ABR abnormalities in the same ear, using the two click polarities:

- ❖ brainstem pathologies caused by demyelination affecting the auditory nerve at different levels (Maurer, 1985; Sand, 1991b; Hammond et al., 1986); and
- ❖ diffuse central conduction abnormality (Chiappa, 1990; Coats & Martin, 1977).

The influence of cochlear pathology and high-frequency hearing loss in these discrepancies is uncertain. The fact that these discrepancies were also observed in Group 1 (with less cochlear pathology and/or high-frequency hearing loss), led to the

conclusion that lesions in the auditory brainstem pathway could have caused these findings.

4.4.8 Summary of results: Sub-aim three

ABR recordings were useful in the detection of neural involvement in the subjects, considering that ABR abnormalities were present in 68 % and 84 % of the subjects, using the R and C click polarities respectively. Several researchers only utilised one click polarity during ABR recordings, and yet the results of the current study indicated that the C click polarity yielded the highest percentage of ABR abnormality and should therefore be included during the recording of ABRs. A possible explanation for this finding was provided by Sand (1991b:296): "The less synchronized C click evoked neural volley, may be more sensitive to central demyelination than the R click evoked volley". Both the R and C click polarity should be presented consecutively. More bilateral ABR abnormalities (indicating bilateral brainstem dysfunction) were illustrated, regardless of the polarity used, which corresponded with Chiappa et al. (1980) and Jerger et al.'s (1986) finding of a higher number of bilateral ABR abnormalities. Table 4.15 illustrates the percentages of abnormal ABRs according to each criterion in both groups using both click polarities.

Table 4.15: ABR abnormalities of both groups using both click polarities

Criteria for ABR abnormality	Group 1	Group 2	Click polarity yielding the highest percentage of ABR abnormality
Absence and/or doubtful identification of waves	17 ears (28,33 %)	12 ears (30 %)	The C click polarity yielded the highest percentage of abnormality for Group 1. The R click polarity yielded the highest percentage of abnormality for Group 2.
Poor repeatability of waves	9 ears (6,57 %)	8 ears (10,2 %)	More ears demonstrated abnormality when using the R click polarity in both groups.
Prolonged absolute latency of waves	3 ears (3,7 %)	3 ears (7,6 %)	Slightly more ears demonstrated abnormal AL when using the R click polarity.
Prolonged interpeak latency of waves	10 ears (8,4 %)	8 ears (7 %)	More ears demonstrated abnormality when using the C click polarity.
Abnormal interaural Wave V latency difference	25,8% of subjects	26,1 % of subjects	The highest percentage of abnormality was illustrated when using the R click polarity.
Abnormal amplitude ratios of Wave V/I	20 ears (35 %)	19 ears (50 %)	More ears demonstrated abnormality when using the C click polarity.

Based on the preceding results, the following criteria for ABR abnormality were found to be clinically useful during the analysis of ABR recordings:

- The presence of waves;
- The ILD of Wave V;
- The amplitude ratio of Wave V/I;
- Reversing the click polarities;
- The IPL of waves should be included as the Wave III-V interval is likely to be prolonged. The area between the suspected anatomic generators (the superior olivary complex and the inferior colliculus) is the longest tract of white matter in the CNS, and therefore the most susceptible to the effects of demyelinating disease (Keith & Jacobson, 1995).

The following criteria for ABR abnormality were not found to be clinically significant during the analysis of ABR recordings:

- The repeatability of waves; and
- The AL of waves.

4.5 REALISATION OF THE MAIN AIM

The purpose of the summary is to combine all the previous results discussed, in order to provide a quantitative and qualitative description of the effectiveness of a multiple test battery approach. Firstly, all the results of sub-aim one, two and three will be tabulated for each group separately. The ABR abnormalities will be tabulated for both ears, since the ILD of Wave V was analysed between two ears. All waves described as *doubtful* were included and interpreted as *abnormal.*

As illustrated in Table 4.16 the first test procedure was the self-assessment questionnaire consisting of information regarding the presence of tinnitus, vertigo and dizziness, followed by the rated hearing abilities (RSEE), and finally communicative competence (COM-C) during every day life. The second test procedure was puretone audiometry. Thirdly the DPOAEs were performed. This was followed by the absence of the CM as seen during the ABR recording. The final test procedure was ABRs using both the R and C click polarities consecutively.

Table 4.16 consists of eight areas, and every subject's bilateral performance, was indicated by an "X" for each of the following:

- When either the presence of tinnitus, dizziness or vertigo was indicated on the self-assessment questionnaire;
- When some degree of hearing difficulty was reported by subjects;
- When subjects experienced communication difficulties during every day life;
- When either ear presented with abnormal puretone thresholds;
- When either ear presented with abnormal DPOAEs;

- When either ear presented with an absent CM;
- If either ear displayed abnormal ABR using the R click polarity; and
- If either ear displayed abnormal ABR using the C click polarity.

The eight points that were allocated as indicated above, were interpreted as follows:

- Subjects who scored either 0/8, 1/8 or 2/8 passed the test battery, and significant auditory-vestibular symptoms and/or auditory involvement were not present;
- Subjects who scored with a total of 3/8, 4/8 or 5/8 will be discussed as the intermediate group; and
- Subjects who scored a total of 6/8, 7/8 or 8/8, failed the test battery.

Table 4.16: Summary of the results for Group 1 and 2

Subject number	Self-assessment questionnaire			Puretone		DPOAEs (outcome 3)		CM		ABR (R)	ABR (C)	Total
	Tinnitus, Dizziness, and/or Vertigo	Some degree of hearing difficulty	COM-C	R	L	R	L	R	L	Either ear	Either ear	
Group 1 15 subjects = 30 ears												
1	X	-	X	X	-	-	-	X		-	X	5/8
4	X	X	X	X	X	X	X			-	X	6/8
5	X	-	X	-	-	-	X			X	X	5/8
6	X	-	X	X	X	-	X			X	X	6/8
8	X	X	X	X	-	-	-			X	X	6/8
9	X	-	-	-	X	X	X			X	X	5/8
11	X	X	X	X	-	X	-			-	-	5/8
15	-	-	-	-	-	-	-	X	X	X	-	2/8
16	X	-	-	-	-	X	-			X	X	4/8
17	X	-	X	X	-	X	X		X	X	X	7/8
18	-	-	-	-	-	-	-			-	-	0/8
19	X	-	X	-	-	-	-			-	X	3/8
20	X	-	X	-	-	-	-	X	X	X	-	4/8
22	X	X	X	-	-	-	-			-	X	4/8
25	X	-	X	-	-	-	-	X	X	X	X	5/8
Total	13	4	11	7		7		4	4	9	11	
Group 2 10 subjects = 20 ears												
2	-	-	-	X	X	-	X		X	X	X	5/8
3	X	X	X	-	X	X	X		X	X	X	8/8
7	-	-	-	-	X	-	-			X	X	3/8
12	-	-	X	X	X	X	X			X	X	5/8
13	X	-	X	X	X	X	X			X	X	6/8
14	-	-	-	X	X	X	X	X	X	X	X	5/8
21	X	-	X	-	X	X	X			X	X	6/8
23	X	X	-	-	-	-	-		X	X	X	5/8
24	X	-	X	X	X	X	X		X	-	X	6/8
26	X	-	X	X	X	X	X			-	X	5/8
Total	6	2	6	9		8		1	5	8	10	

X = failed the test procedure
R = Right ear
L = Left ear
(R) = Rarefaction click polarity
(C) = Condensation click polarity

The summary of results were as follows:

- Two subjects from Group 1 passed the battery of test procedures;
- Another eight subjects failed the battery of test procedures, and were equally distributed between the two groups.
- Fifteen subjects were described as the intermediate group of whom 9 subjects belonged to Group 1.

Those subjects (no. 15 & 18) who *passed* the battery of test procedures did not experienced clinically significant auditory-vestibular symptoms, hearing difficulties and/or communication difficulties during every day life. Only subject no. 15 presented with bilateral absence of the CM and unilateral abnormal amplitude ratio of Wave V/I, using the R click polarity. The fact that a multiple test battery was used to assess these subjects' auditory nervous system provided a more comprehensive understanding of their auditory abilities.

Those subjects who *failed* the battery of test procedures displayed auditory involvement of either a cochlear and/or neural nature, with corresponding hearing complaints and related symptoms. It was expected that more subjects in Group 2, with a risk for noise-induced hearing loss, would fail the test battery, but this was however not the case.

The *intermediate group* illustrated the complexity and high variability of different types of auditory-vestibular symptoms, cochlear and/or neural involvement between subjects and once again stressed the importance a of a multiple test battery approach. This group of subjects' auditory nervous system should be assessed on a regular basis using a multiple test battery approach to detect any changes during the course of the disease.

When comparing the findings of all the tests procedures, more subjects from Group 1 reported hearing difficulties, the presence of related auditory-vestibular symptoms and communication difficulties during every day life. In Group 2 more subjects demonstrated impaired puretone thresholds and abnormal DPOAEs, indicating a high percentage of cochlear involvement in this group, possibly due to a history of noise exposure.

Furthermore all of the subjects in Group 2 displayed ABR abnormality using the C click polarity indicating additional neural involvement.

The multiple test battery approach was sensitive in determining the nature and degree of auditory involvement in subjects with Multiple Sclerosis. This approach was also specific in identifying those subjects without any obvious symptoms and auditory involvement. The use of a multiple test battery contributed towards forming a comprehensive view of the auditory-vestibular symptoms and auditory involvement of subjects with Multiple Sclerosis, and should include the following.

The **self-assessment questionnaire** assessing the:

- presence of **tinnitus;** since the number of subjects who reported this auditory related symptom increased during the course of the disease. Hearing loss is reported to be the primary risk factor for subjective tinnitus (Chung et al., 1984). The researcher concluded that the presence of tinnitus was the result of outer hair cell damage (in most of the cases). However, some of the subjects also displayed ABR abnormalities (using either the R or C click polarity), and the question whether brainstem abnormalities also contributed to the presence of tinnitus remains unsolved.

- subjective perception of **hearing abilities;** since the number of subjects who experienced hearing difficulties as an initial MS-related symptom increased during the course of the disease. Whether subjects' perception of hearing difficulties was solely due to cochlear hearing loss remains uncertain, since some subjects also demonstrated ABR abnormalities (using both polarities) and the perception of hearing difficulties could be attributed to neural auditory involvement.

- perception of **communicative competence during every day life;** since this would also describe the various scenarios where communication difficulties were experienced during every day life. In most cases sensory involvement was

present in subjects who reported communication difficulties, although a small number of subjects only presented with neural involvement, despite complaining of communication difficulties.

The multiple test battery should also include procedures to assess the degree of auditory involvement and procedures to determine whether this involvement is the result of cochlear damage and/or neural involvement.

- **Puretone audiometry** was included to determine the extent of hearing impairment and the configurations of affected audiograms. Although this test procedure does not supply information regarding the site-of-lesion, it was valuable when used in combination with other test procedures.

- The analysis of the **CM** as seen during ABR recordings was applied to determine hair cell involvement. In some cases the absence of the CM and abnormal DPOAEs resulted in the diagnosis of definite cochlear involvement, although most of the ears demonstrated the presence of the CM in the absence of some DP points. The effectiveness of the CM (applied in isolation from the DPOAE findings) in the differential diagnosis of inner ear/auditory nerve disorders was not found to be clinically significant during the current study. When used in combination with the DPOAE findings, it resulted in the conclusion that inner hair cell activity could have contributed to the presence of the CM in some ears with abnormal DPOAEs.

- The **DPOAE** is an objective test procedure to detect outer hair cell involvement and should therefore be included as part of the multiple test battery. Even subjects who were not exposed to high levels of noise presented with cochlear involvement, indicating that the perception of MS, as being a disease that only affects the brainstem structures, could be questioned. The CM and DPOAE alternations found in subjects in the current study provided a strong presumption that cochlear functions can be involved in this disease. This finding was verified by a study on auditory neuropathy by Starr et al. (2001). They were however

unable to distinguish whether the alternations of cochlear hair cell functions were a cause or a consequence of disordered auditory nerve activity considering that auditory nerve function could also be impaired if the site of the lesion was the inner, outer hair cells and/or the synapse between the inner hair cells and the VIIIth nerve dendrite (Harrison, 1998). Due to this uncertainty, ABR recordings should be included in the test battery.

- One might question the effectiveness of **ABR** recordings used on subjects with hearing impairment since the degree and configuration of the audiograms can influence the ABR recordings. This was however not the case in the current study. Most of the high-frequency hearing losses were not steep and of a mild to moderate degree. Hood (1998) stated that if the hearing loss is less than 60 dB HL and cochlear in origin, then normal ABRs to high-intensity clicks are the expected result. The expected ABR abnormalities in conjuction with high-frequency hearing losses are that of prolonged or absent Wave I, or sometimes reduced Wave I-V IPL. These expected abnormalities were addressed by adjusting the stimulus and acquisition parameters such as, presenting a slow stimulus rate, increasing the stimulus intensity and using insert earphones. Although absent and poor repeatability of Wave I was found in some ears, no prolonged Wave I or reduced Wave I-V IPL were observed. As mentioned previously, the degree of high-frequency hearing loss, could not have contributed to the abnormalities of Wave I, as was previously observed in the literature regarding MS. Abnormalities of Wave I have been interpreted as involvement of the distal VIIIth nerve.

  The ABR recordings, using both the R and C click polarities consecutively, were especially effective in the current study considering that the use of a single click polarity did not detect abnormality in some cases. It was also possible to detect the CM after reversing the click polarities and a high number of discrepancies between different types of ABR abnormality were observed, even in the same ear.

The ABR was also specific in identifying two subjects with bilateral normal ABRs using both the R and C click polarities. When comparing the ABR recordings with the results of puretone audiometry and DPOAEs, it was found that the ABR recordings were sensitive in the detection of six subjects' displaying only auditory brainstem involvement, possibly due to their disease. In these cases lesions in the brainstem have not yet resulted in impaired puretone thresholds and cochlear involvement. Thus a certain level of synchronisation was sufficient for the perception of puretones, but not for the formation of waveforms (Özünlü et al, 1998). Dirks' (1978) statement that the CANS is resistant to hearing loss of the type measured by puretone audiometry was confirmed. It was interesting to note that five of these subjects were of the opinion that they experienced some degree of hearing impairment and/or reported communication difficulties during every day life. These results were also demonstrated in a single case study performed by James et al. (1983).

In five subjects, ABRs were effective in detecting abnormalities associated with possible sensory involvement. The presence of sensory involvement was uncertain, considering that either unilateral abnormal DPOAEs or unilateral impaired puretone thresholds were found. Outer hair cells receive a rich efferent innervation from the CNS and the interaction of DPOAEs with external stimulation reflects the influence of the CNS on the operation of the cochlear biomechanical system (Robinette & Glattke, 2000). Therefore abnormal DPOAEs could be measured in the presence of CNS abnormality. Hall (2000) reported retrocochlear auditory dysfunction with concomitant cochlear deficits associated with different types, sizes and locations of tumors. Ohlms et al. (1990) noted mildly reduced DPOAEs in patients with retrocochlear lesions. The researcher could however not trace any studies regarding the effects of demyelinating disease on the cochlear function, thus the results of abnormal ABRs as well as DPOAEs, are difficult to explain. The only studies measuring DPOAEs in patients with Multiple Sclerosis were performed during single case studies with sudden loss of hearing. Normal DPOAEs were found in the presence of abnormal ABRs (Robinette & Facer, 1991; Nishida et al., 1995; Cevette et al.,

1995). Considering that four of these subjects presented with bilateral CMs, led the researcher to conclude that abnormal unilateral DPOAEs or impaired unilateral puretone thresholds, might have been the result of neural involvement.

The multiple test battery approach was also effective in confirming the presence of **silent or subclinical lesions** in the auditory pathways of subjects with Multiple Sclerosis. This implies that the ABRs should detect auditory brainstem involvement in the absence of clinical findings or reported auditory-vestibular symptoms (Jacobson & Jacobson, 1990). Three subjects reported no tinnitus, vertigo, dizziness, hearing complaints or communication difficulties but presented with abnormal ABR recordings using either the R or C click polarity.

A clinically appropriate battery of test procedures was effective during the assessment of the auditory nervous system of subjects with Multiple Sclerosis. Even in Group 1, no single pattern of auditory involvement could be observed. Due to the high variability of findings between the subjects, the diverse nature of the disease, the complexity of the auditory nervous system and the fact that an audiologist can encounter patients with Multiple Sclerosis who have been exposed to high levels of noise, a multiple test battery approach should be implemented.

4.6 SUMMARY OF CHAPTER 4

In this chapter the results obtained in the current study were discussed according to the three specified sub-aims. These sub-aims were selected in an attempt to answer the main aim of the study. Each sub-aim provided results that were discussed and integrated with current literature to ascertain the validity thereof. A summary of results was compiled from the findings obtained in each sub-aim, and supplied at the end of the chapter. The results provided the empirical study with some clinical implications for future research and applications in the clinical setting.

CHAPTER 5

CONCLUSIONS, IMPLICATIONS AND RECOMMENDATIONS

5.1 INTRODUCTION

The main aim of the current study was to examine the contribution of a multiple test battery approach, in order to determine the clinical appropriateness of such a test battery. The multiple test battery assessed the subjects' self-perception of their hearing abilities, associated auditory-vestibular symptoms, communicative competence during every day life as well as the sensory and neural auditory nervous system. Conclusions drawn from each test procedure, including the implications of the results obtained will be discussed. This will be followed by a critical evaluation of the research method used in the current study. A discussion of the major clinical and theoretical implications will be provided. General aspects regarding the auditory system of patients with Multiple Sclerosis that emerged from the auditory assessment during the current study, as well as previous studies, will then be discussed. This will be followed by recommendations for future research. Despite the discussion of results in Chapter 4, three additional figures were included in Chapter 5.

5.2 CONCLUSIONS

One of the most significant findings of the current study was the relatively high prevalence of auditory and vestibular involvement found in subjects with Multiple Sclerosis, which could be conclusively identified with a multiple test battery approach. The findings of the multiple test battery demonstrated that 96 % of the subjects reported auditory-vestibular symptoms and/or presented with sensory and/or neural auditory involvement when tested with several audiometric test procedures.

The battery of test procedures selected for the current study proved to be effective and sensitive in detecting auditory involvement during the assessment of the auditory nervous system of subjects with Multiple Sclerosis. The results provided support for the application of a multiple test battery approach.

The following information provides a general overview of the results obtained during the application of the multiple test battery approach. It is important to draw some conclusions on the contributions of each test procedure, not necessarily related to the statistical significance thereof.

5.2.1 The contribution of the self-assessment questionnaire

One of the positive contributions of the self-assessment questionnaire was that it offered the opportunity to actively involve the subjects during the audiometric assessment. The subjects reported on their auditory-vestibular symptoms as well as their hearing abilities and communication competence during every day life.

- *Initial auditory-vestibular symptoms.* Although the prevalence of vertigo, hearing difficulties and tinnitus were rarely reported as part of the subjects' *initial* MS-related symptoms, these numbers seemed to increase *by the time of the current study*. Since the symptoms of the disease can fluctuate and are progressive in nature, it is important to continuously assess these symptoms during the course of the disease.

- *Auditory-vestibular symptoms reported during the current study.* Most of the subjects reported the presence of dizziness and vertigo at the time of the current study. These symptoms can be indicative of VIIIth nerve involvement warranting the assessment of the vestibular system by using ENG measurements. In the current study only a few subjects reported the presence of tinnitus, which can be a symptom of cochlear, VIIIth nerve and/or central auditory involvement. Although Nishida et al. (1995) reported the prevalence of tinnitus to be less than 10 % in patients with Multiple Sclerosis, it has preciously been associated with

demyelinating diseases (Lechtenberg & Shulman, 1984). The presence of tinnitus warrants further audiometric assessment to determine the possible site-of-lesion.

- *Subjective perception of hearing abilities.* A high percentage of subjects were of the opinion that their hearing abilities were *good* in both ears even though other test procedures indicated cochlear and/or neural involvement. Hearing difficulties were experienced as insignificant when compared to other MS-related symptoms, and subjects did not feel that it affected their quality of life. Due to the presence of mild unilateral hearing impairment and silent lesions without corresponding hearing complaints, many subjects might have been unaware of impaired hearing sensitivity. It is important that patients undergo a comprehensive hearing assessment since silent lesions and mild hearing impairment can be detected during the audiometric assessment, as was the case in the current study.

- *Communicative competence during every day life.* Despite the low percentage of subjects reporting hearing difficulties in both ears, many subjects experienced communication difficulties during every day life. This possibly underlines the subjects' lack of awareness regarding the relationship between hearing loss and communication competence. It is important for audiologists to include a rating scale and/or ask specific questions regarding communicative competence during every day life as part of the audiometric assessment. The descriptions obtained did not enable the researcher to ascertain a possible site-of-lesion, but when used in combination with other differential diagnostic test procedures, it provided a more comprehensive view of each subject's auditory functioning.

5.2.2 The contribution of puretone audiometry

Other audiometric test procedures should not be excluded when ears present with normal puretone thresholds (as was the case in six subjects displaying bilateral normal puretone thresholds), since some of these ears presented neural involvement. On the other hand all of these subjects reported the presence of tinnitus, vertigo, dizziness, some degree of hearing difficulty and/or communication difficulties during every day life. Therefore the

presence of any subjective complaint, despite normal hearing sensitivity, necessitates further assessment using site-of-lesion test procedures.

Despite the low percentage of subjects displaying abnormal puretone thresholds (30 % of subjects in Group 1), the presence of a hearing loss raises an interesting theoretical question. Does MS cause the audiometric deficit or were the observed hearing losses due to other unrelated factors such as aging, noise trauma and ototoxic drugs? The problem is complicated by the fact that many different audiometric configurations were observed in the puretone thresholds of patients with Multiple Sclerosis. Care was exercised in controlling the contaminating effects of these unrelated factors during the current study. It can be concluded that MS was the cause of at least some, if not most, of the commonly observed high-frequency hearing losses, especially the unilateral hearing losses and rising configurations found in Group 1.

5.2.3 The contribution of DPOAEs and the CM in conjunction with puretone audiometry

The inclusion of DPOAEs and CMs as part of the multiple test battery provided the researcher with the opportunity to assess the subjects' cochlear function, an aspect not frequently included in previous studies. Figure 5.1 illustrates the results of DPOAEs and CMs in conjunction with the findings of puretone audiometry.

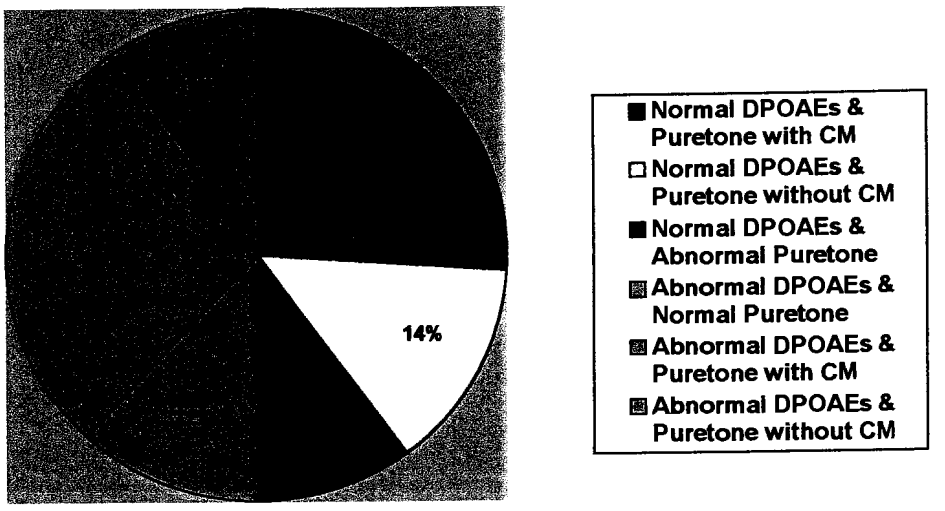


Figure 5.1: Concluding findings of DPOAEs and CMs in conjunction with the results of puretone audiometry

- **Normal DPOAEs and puretone thresholds with an observable CM** were present in 26 % of ears, indicating the absence of sensory involvement.

- **Normal DPOAEs and puretone thresholds without an observable CM** were present in 14 % of ears, indicating normal outer hair cell function, but possibly some inner hair cell involvement and thus sensory involvement of some kind.

- **Normal DPOAEs and abnormal puretone thresholds** were present in 10 % of ears, indicating normal outer hair cell function. This finding could have been the result of neural involvement. The CM was absent in only one ear and some degree of cochlear involvement could be argued.

- **Abnormal DPOAEs and normal puretone thresholds** were present in 12 % of ears, indicating subtle cochlear involvement without affecting the puretone thresholds. The CM was absent in one ear due to outer and/or inner hair cell involvement. DPOAE measurement was more sensitive in detecting outer hair cell involvement than the analysis of CMs, in these ears.

- **Abnormal DPOAEs and puretone thresholds with an observable CM** were present in 28 % of ears, specifically indicating outer hair cell involvement.

- **Abnormal DPOAEs and puretone thresholds without an observable CM** were present in 10 % of ears, indicating sensory involvement.

Twenty-six percent of the ears that displayed abnormal DPOAEs and puretone thresholds belonged to Group 2, and the hearing impairment could also have been the result of noise exposure. However, a percentage of these abnormal findings could also be the result of MS.

The CM was present in 46 % of ears in conjunction with abnormal puretone thresholds and/or DPOAEs. Hall (2000) also reported this finding, especially if the receptor potentials remained intact, while the complex mechanisms involved in active processes (motility) were disrupted. Additionally, the fact that the CM generation is not entirely dependent on outer hair cell functioning, but also due to some inner hair cell contribution, the CM in the absence of some DPOAEs may indicate normal inner hair cell function. The analysis of the CM in the current study was useful, but cannot be effectively applied and interpreted without including DPOAEs.

5.2.4 The contribution of ABRs in conjunction with DPOAEs

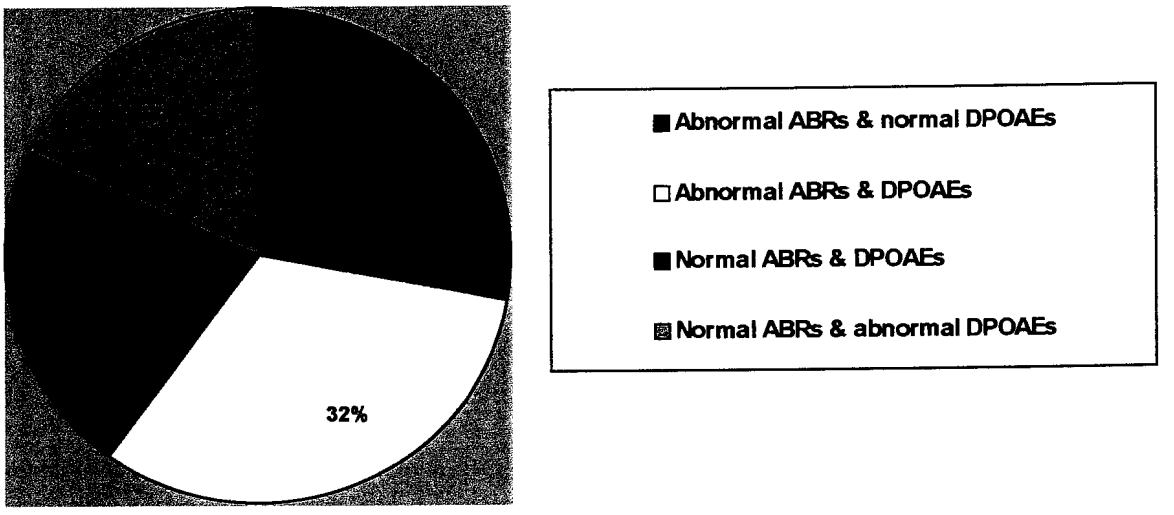


Figure 5.2: Concluding findings of ABRs (using the R click polarity) in conjunction with DPOAEs

By performing an objective test procedure such as ABR in conjunction with DPOAEs, a differential diagnosis could be made between cochlear and retrocochlear/neural involvement (Hall, 2000). It was concluded that the highest number of ears (32 %) displayed both cochlear and retrocochlear involvement (as determined by abnormal ABRs and DPOAEs), whereas fourteen ears presented only with neural/retrocochlear involvement. Ten of the ears (20 %) displaying both cochlear and retrocochlear involvement belonged to Group 2.

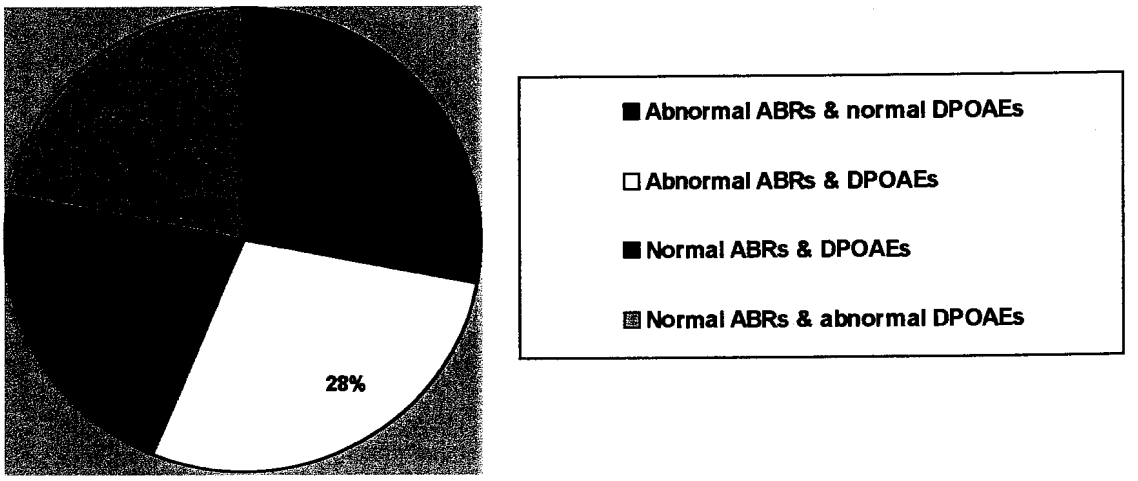


Figure 5.3: Concluding findings of ABRs (using the C click polarity) in conjunction with DPOAEs

An equal number of ears (28 %) displayed either only retrocochlear/neural involvement or both cochlear and retrocochlear involvement. Similar numbers were illustrated in Figure 5.2 when using the R click polarity. Eleven ears demonstrated both normal DPOAEs and ABRs using the C click polarity, and these ears presented with normal cochlear and neural functioning. Only eleven ears (22 %) presented with only outer hair cell involvement, since DPOAEs abnormality was found in 4 ears from Group 1 and 7 ears from Group 2, in the presence of normal ABRs. The inclusion of ABR recordings and DPOAEs were valuable during the assessment of subjects with Multiple Sclerosis.

5.2.5 The contribution of ABRs using both the R and C click polarities

The criterion for ABR abnormality that yielded the highest percentage of abnormality (using either of the click polarities) was the amplitude ratios of Wave V/I, followed by the absence of waves and the ILD of Wave V. The C click polarity yielded the highest percentage of unilateral or bilateral auditory involvement on a brainstem level. Additionally, reversing the click polarities illustrated valuable findings. A high percentage of ears illustrated R versus C click polarity discrepancies between different types of ABR abnormalities. This can be indicative of lesions at different levels of the auditory pathway. A small number of ears demonstrated similar abnormalities using both click polarities.

It was concluded that all the test procedures selected as part of the multiple test battery approach were effective when used in combination with each other, but not in isolation. The results of the current findings also demonstrated that the test procedures were sensitive to both sensory and neural auditory involvement in a group of adults with Multiple Sclerosis. This study provided a framework towards better understanding of the disease, and the effect it has on the auditory nervous system. Audiologists performing diagnostic measurements need to understand the usefulness and importance of applying a multiple test battery approach during the assessment of the auditory nervous system of patients with Multiple Sclerosis. These results can supplement other assessments involving evoked potentials and clinical neurological evaluations. The audiometric assessment of a patient with Multiple Sclerosis can also provide guidelines for assistance with auditory problems, for example: assistive listening devices, as well as monitoring the changing effects of the disease.

5.3 CRITICAL EVALUATION OF THE CURRENT STUDY

The research question was whether a clinically appropriate battery of test procedures would be able to effectively describe the auditory involvement of patients with Multiple Sclerosis. In other words the multiple test battery should accurately identify those patients with auditory involvement and not those without. In answering this question the primary criteria are based on the **reliability** and **validity** of the test procedures (Roeser et al. 2000).

5.3.1 Reliability of the current study

Reliability refers to *consistency* (Roeser et al., 2000): to what extent will the test results correlate if the test procedures are administered, and then repeated at a different time by the same or different individual. The reliability of a test must be high for it to be viewed as effective. The reliability can be controlled and maintained at a high level by standardising test administration, ensuring proper equipment calibration, and controlling patient variables (Roeser et al., 2000).

- The reliability of the **self-assessment questionnaire** was high since this test procedure assessed the subjects' perceptions of hearing difficulties, auditory-vestibular symptoms and communicative competence during every day life. Several cross-checked questions were added and answers were confirmed verbally to determine accuracy before the onset of the audiometric assessment.

- **Puretone audiometry** is subjective in nature due to the fact that patient participation is required. Reliability was increased by preparing each subject for the testing, ensuring that instructions were understood (Roeser et al., 2000). Effective co-operation was received from all of the subjects. No false positive responses were observed during threshold determination.

- Gaskill and Brown (1990) found **DPOAE measurements** to be extremely stable over time, and in the current study DPOAEs were only analysed when at least two DPgrams were repeatable. Therefore DPOAEs seem to be reliable measurement.

- According to Hall (1992) **ABR** recordings are reliable if the tracings are repeatable. However, poor morphology and repeatability of waves made identification of waves difficult in some cases. Furthermore Garza et al. (1982); Prasher and Gibson (1980) and Robinson and Rudge (1980) found the test-retest reliability of ABR recordings to be poor in patients with Multiple Sclerosis.

The last aspect that also played a role in the reliability of the current study was human error during data preparation, analysis, and processing. Human errors were reduced where possible by electronic preparation, analysis and processing of data. However, the analysis of ABR recordings, such as the presence of waves, and especially the repeatability of waves, remains a subjective analysis. Due to this, the results of all the audiometric test procedures were analysed by a panel of audiologists. All test procedures implemented were measured as accurately as technology currently allows on calibrated equipment.

5.3.2 Validity of the current study

Not only must the test procedures and results be reliable, it must also identify the problem for which it is being conducted. The test procedures should be a valid measure of the disorder for which it was designed. The validity of test procedures and the results should correctly identify subjects with disorders (sensitivity), and not those without (specificity) (Roeser et al., 2000).

- The **self-assessment questionnaire** was *sensitive* to communication difficulties during every day life and vestibular symptoms experienced by the subjects. Furthermore the *specificity* was high for rating their hearing abilities and auditory symptoms such as tinnitus.

- **Puretone audiometry** was a valid test procedure for determining if the hearing sensitivity of subjects was affected, as well as supplying information on the degree, configuration and type of hearing impairment.

- **OAEs** are a valid auditory measurement with *high sensitivity* in detecting even subtle cochlear dysfunction involving the outer hair cells. No reference was made regarding the specificity of DPOAEs (Hall, 2000).

- Jerger and Jerger (1983) and Musiek et al. (1983) reported that **ABR recordings** had unusually high sensitivity and specificity rates. The criteria for ABR abnormality in the current study were defined as abnormalities found using either the R or C click polarities (and not both), and this resulted in *higher sensitivity* but *lower specificity*. Valid ABR recordings are dependent on the hearing sensitivity and audiometric configuration (Arnold, 2000). The high-frequency hearing losses found in the current study was of a mild degree, and the configurations of the affected audiograms were not steep, thus not affecting the validity of the ABR recordings.

5.4 CRITICAL EVALUATION OF THE RESEARCH METHOD

5.4.1 Subject collection procedures

Subjects were recruited by accidental sampling. Additionally a notice was published in the South African MS Society' newsletter. This method could be viewed as biased if only subjects with hearing difficulties responded to the notice. However, this was not the case seeing that only three of the twelve subjects who responded to this notice were of the opinion that they experienced hearing difficulties.

Information on whether subjects were smoking was not included as one of the criteria for subject selection. Smoking is related to hearing loss and indirectly affects the prevalence

of tinnitus (Chung et al., 1984). Therefore, it is suggested that subjects who smoke be excluded in future research studies.

5.4.2 Research subjects

Although the sample was representative of both sexes and a wide range of ages, convenience/accidental sampling does not allow for generalisations and inferences of results to the MS population.

5.4.3 Medical information of the subjects

Although all the subjects were diagnosed with Multiple Sclerosis, the number and sites of brainstem lesions, as well as involvement of the auditory pathway were not known to the researcher. It would have been possible to obtain this information from subjects' neurologists. However, this information would not have been reliable owing to the following reasons:

- some of the subjects did not attend their annual neurological examinations;
- others received a MRI by the time of diagnosis, a mean range of 4,7 years before the current study;
- the course of the disease varies over time;
- the symptoms vary from one patient to another; and
- MS is progressive in nature.

The fact that the medical history of the subjects was not known implies that no correlation can be drawn between the findings of the current study, and the number of known or suspected brainstem lesions. This can be viewed as a limitation of the current study.

5.4.3.1 Physical severity of the subjects

No differentiation was made between the different severities of MS. Some of the subjects experience no difficulty with walking, whereas others used walking sticks and

some were wheelchair bound. Although some reports found a correlation between the number of auditory abnormalities and the severity of the disease, it could have been useful to compare the number of auditory abnormalities found in the current study with the physical severity of the disease.

5.4.4 Clinical usefulness of material and apparatus

The test procedures that were selected as part of the multiple test battery for the current study are available at most universities and educational hospitals, but only in some audiology practices. The necessary referrals ensuring the implementation of the suggested multiple battery of test procedures can however minimise this problem during the assessment of the auditory nervous system of patients with Multiple Sclerosis.

- The rating scales applied in the **self-assessment questionnaire** were easy to complete ensuring reliable results. A self-assessment questionnaire can be completed during the neurologist clinical examination, and the necessary referrals made. Only 19 % of the subjects in the current study had previously been referred for a complete audiometric assessment. This low percentage proves that there is as of yet no effective team approach in place between neurologists, general practitioners and audiologists.

- **Puretone audiometry** forms the foundation of every audiometric test battery, and although valuable information regarding hearing sensitivity was obtained it should not be used in isolation during the assessment of patients with Multiple Sclerosis.

- By including **DPOAEs** and **CMs**, an objective cross-check measurement of the cochlear function in subjects with Multiple Sclerosis were provided. The results of the DPOAEs and CMs were compared to abnormal puretone thresholds to confirm sensory involvement. Furthermore a correlation was found when the affected octaves of the DPgram were compared to the configurations of the affected audiograms.

- Except for **ABR recordings**, no other test procedures were selected to provide a powerful cross-check on localisation of auditory function and dysfunction within the brainstem. Jerger et al. (1986) found that the ABR receives no special advantage above other measurements such as AR, speech audiometry and MLD. A high percentage of abnormality, using sophisticated analysis of AR waveforms, was illustrated. Hannley et al. (1983) stated that the ABR and MLD had an equally high rate of identification accuracy, and according to Lynn et al. (1980) the MLD offered a test instrument not only sensitive to retrocochlear disorders, but it also offers specificity. Levine et al. (1994) found interaural time discrimination for high-frequency sounds to be the most sensitive in detecting brainstem lesions when compared to other tests procedures.

5.4.5 Data analysis procedures

Much of the disagreement among previous investigators regarding the prevalence of a given auditory abnormality can be traced to variation in criteria of abnormality. To determine abnormal hearing sensitivity, several criteria can be used:

- Northern and Downs (1991) classified normal hearing sensitivity for adults, when puretone thresholds are between 0 – 25 dB HL, which would have resulted in less subjects displaying abnormal puretone thresholds.
- Martin and Champlin (2000) proposed that 15 dB HL, rather than 25 dB HL must be considered as the upper limit of normal hearing sensitivity considering that so many people with hearing thresholds worse than 15 dB HL experienced difficulty with hearing. Using this classification system in the current study would have resulted in an increased number of ears with slight hearing losses, explaining the high number of subjects experiencing difficulty with communication during every day life.
- During the current study puretone thresholds were expected to be between 0 - 20 dB HL to be considered as normal, and may not be sensitive enough in detecting slight hearing losses.

Differences in ABR analysis may have a substantial effect on the estimated prevalence of abnormality, especially for ABR absolute latencies. During ABR analysis investigators used a:

- 95 percent criterion (i.e., a result is abnormal when it exceeds the mean ± 2 SD from the normative data); or a
- 99 percent criterion (i.e., a result is abnormal when it exceeds the mean ± 3 SD from the normative data).
- For the current study a ± 2,5 SD from the mean, an interaural latency of greater than 0.4 ms for Wave V and the V/I amplitude ratio below 1.0 mV was considered to be abnormal. More ears would have presented with AL and IPL abnormalities if a ± 2 SD from the mean had been used to determine ABR latencies.

The ABR recordings and DPOAEs measurements were analysed according to norms established at other facilities, since norms were not available at the facility were test procedures were performed. The published norms used for the analysis of DPOAEs and ABR recordings were however developed for the same instruments used during the current study.

5.5 IMPLICATIONS FOR THE MEDICAL PROFESSION AND THE MS POPULATION

The current study provided several theoretical and clinical implications for audiologists, as well as for the medical profession, and the MS population as a whole. The MS population, support groups and medical profession, especially neurologists and general practitioners, should be aware of the fact that the disease can affect the auditory nervous system at several levels. Questions regarding hearing abilities, auditory-vestibular symptoms and communicative competence during every day life should routinely be included during the medical evaluation of patients with Multiple Sclerosis. Patients should be encouraged to report any change in their hearing abilities and related auditory-vestibular symptoms such as tinnitus, vertigo and dizziness during the course of the

disease. Increased patient awareness regarding hearing abilities, auditory-vestibular symptoms and communicative competence during every day life will result in the referral of patients to audiologists and ear-, nose- and throat specialists, ensuring a comprehensive assessment and management. This could ultimately increase quality of life and improve the overall well-being of patients with Multiple Sclerosis.

5.6 RECOMMENDATIONS FOR CLINICAL USE (CLINICAL IMPLICATIONS)

- A multiple test battery approach should be followed during the audiometric assessment of patients with Multiple Sclerosis.
- The multiple test battery should include information regarding the patients' subjective perception of hearing abilities, auditory-vestibular symptoms and communicative competence during every day life. This information can be obtained through the use of a self-assessment questionnaire and/or personal interview.
- Test procedures should assess the auditory nervous system on several levels by including puretone audiometry, DPOAEs, the CM and ABRs.
- The presence of a CM as seen during ABR recordings does not exclude DPOAEs from the battery of test procedures since it may reflect the function of the inner hair cells while DPOAEs can supply information on the outer hair cell function. Abnormal DPOAEs can be found despite the presence of the CM.
- The R click polarity was most often used in studies utilising ABR recordings. As seen in the current study only a limited number of ABR abnormalities were observed during the presentation of R click polarity, while the C click polarity yielded a higher percentage of abnormality. Furthermore R versus C click polarity discrepancies would not have been detected with only the use of one click polarity. Due to the high variability of abnormalities found between the results obtained, by using the R or C click polarity, ABR recordings should include both of these polarities performed consecutively.

- A high percentage of abnormal Wave V/I amplitude ratios were present during ABR recordings in the current study. The inclusion of this criterion to determine ABR abnormality should be considered during other clinical investigations. Musiek et al. (1989) have also concluded that this parameter should be included during the determination of ABR abnormality.
- Improved comparisons between the auditory findings and the level of CNS involvement will result from knowledge regarding the presence of clinical or radiological evidence of brainstem involvement.
- Due to the nature of the disease, any abnormal audiometric pattern may result and this pattern can be expected to change during the course of the disease.
- Several clinical implications need to be considered by the audiologist in the management of patients with Multiple Sclerosis. Patients with combined cochlear and neural involvement could be fitted with non-linear hearing instruments, while the use of FM-systems are recommended for those patients with neural involvement, as well as those experiencing communication difficulties during every day life.

5.7 RECOMMENDATIONS FOR FUTURE RESEARCH

Several significant aspects requiring further investigation were revealed by the results obtained, and conclusions drawn from the current study. The following specific recommendations apply to future research:

- The current study can be repeated using a similar multiple test battery approach for the assessment of changes due to increased duration and severity of symptoms (longitudinal tracking).
- Due to the lack of available normative values for DPOAE and ABR recordings, it is advisable to use a control group of similar gender and age as the sample group.
- Patients with Multiple Sclerosis could serve as a pathology group to study particular aspects of processing, such as OAE suppression.
- A wider spectrum of audiometric test procedures to assess different aspects of the hearing phenomenon in patients with Multiple Sclerosis should be added to the

current battery of test procedures. This will increase the validity of test results. For example: electrophysiological tests such as AR, MLR, LVR and EcochG can be used in future research. The MLR and the LVR will provide more information on the central auditory system, and specifically the auditory cortex. The P300 (late or long auditory evoked potential) could be implemented to assess auditory subcortical brain structures of patients. These test procedures should be used in cohesion with neurological findings.

- Most patients with Multiple Sclerosis experienced vestibular symptoms such as dizziness, vertigo and balance disturbances during the course of the disease. ENG measurements could assess these symptoms to determine whether it is related to a peripheral or central vestibular disorder. Due to the pathophysiology of the disease, a more central vestibular lesion may account for these symptoms.
- A similar study can be performed on patients who are newly diagnosed with Multiple Sclerosis. Not only will the MRI findings be available, but the site-of-lesions (caused by plaques), will also be known. This will allow for comparison between radiological and audiometric test results. Conclusions regarding the reliability and validity of audiometric test procedures used on patients with Multiple Sclerosis can be determined.
- Since the ABR amplitude measures vary considerably (Musiek et al., 1989), further investigation of this parameter should be performed.
- More audiological research is required on patients with other degenerative disorders such as Charcot-Marie-Tooth disease, Alzheimer as well as other neurological diseases, such as Parkinson's disease and Neurofibrosis.

5.8 FINAL COMMENTS

The ultimate goal of audiological assessment should be to perform a cost-effective and clinically effective battery of test procedures, in order to ensure comprehensive assessment of the auditory nervous system of patients with Multiple Sclerosis at several levels. The effective management of patients with Multiple Sclerosis should include regular monitoring of their auditory nervous system and resulting rehabilitation needs.

These needs may vary and should be individualised according to specific needs. Only through continuous research of neurological diseases like MS, can the most appropriate multiple test battery approach be identified, and management guidelines be developed and refined. **"A test battery is the foundation of responsible and effective auditory assessment" (Hannley, 1986:1).**

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APPENDIX A

AN OVERVIEW OF MULTIPLE SCLREROSIS

AN OVERVIEW OF MULTIPLE SCLEROSIS

The purpose of Appendix A is to provide a description of the neurological disease known as Multiple Sclerosis. The name "Multiple Sclerosis" refers to the two features of the disease:

The first feature is that scattered (multiple) areas in the central nervous system (CNS), especially the white matter surrounding the ventricular system of the cerebral hemispheres, the brainstem, cerebellum, optic nerves and the spinal cord, are affected by demyelination (Lechtenberg, 1995). Demyelination is the process during which the myelin sheaths are damaged or stripped from the nerve fibres. Nerve fibres that are covered with an insulating myelin sheath are described as myelinated, and this insulation is as vital to the transmission of information-carrying signals as the fibre itself. It allows for faster conduction of impulses along the nerve fibre, as well as improved transmission of closely spaced impulses. Demyelination slows down or blocks the neuro-transmission of impulses by the nerve.

The second feature of the disease refers to the appearance of hardened (sclerotic) patches in the involved (or demyelinated) areas of the brain and spinal cord. These sclerosed patches are called plaques (Lechtenberg, 1995).

Approximately 70 % of patients affected by Multiple Sclerosis are between 20 and 40 years of age at the onset (Grénman, 1985), and there is a predilection for females of about 2 to 1 (Lechtenberg, 1995). Differences in the prevalence rates for people living at different altitudes have been well established (Knight, 1992). Temperate zones more remote from the equator are higher risk zones than those closer to the equator (Lechtenberg, 1995). Individuals growing up in tropical regions, such as equatorial Africa or South America, usually do not develop MS. In the northern part of the United States, Northern Europe and Canada, the prevalence is about 30-80/100 000. Dean (1967) reported that the prevalence for white Afrikaans speaking natives was 3/100 000, and for white English speaking natives it was 11/100 000. It was also found that most patients with Multiple Sclerosis in South Africa were immigrants from Europe, with a prevalence of 50/100 000. This rate is equivalent to that found in their country of origin.

The diagnosis of MS is still clinical in nature, aided by laboratory investigations such as evoked potential measurements, cerebrospinal fluid assay, blood tests, computerised tomography (CT) and magnetic resonance imaging (MRI) (Hallpike, 1983). In order for MS to be diagnosed the patient must be of an appropriate age, and must have experienced at least two remitting episodes of neurological disturbances, implicating two distinct sites of involvement in the CNS (McDonald & Silberberg, 1986). The typical clinical course of the disease is one of relapses and remissions, yet usually progressive. Episodes of acute symptoms are followed by periods of improvement, sometimes with complete remission, or with residual symptoms or deficits. In some cases the disease takes a chronic progressive course without remissions (Grénman. 1985). The pathology and symptom pattern of MS is highly variable, and thus it should come as no surprise that the course and prognosis for the disease is equally unpredictable (Knight, 1992). Pathological studies demonstrated the presence of clinically "silent" demyelinating lesions. Silent lesions are those that do not result in apparent symptoms, but can be identified by radiological or electrophysiological studies (Riviera, 1990). The symptoms of patients with Multiple Sclerosis may vary greatly from patient to patient, as well as over time in each individual (Lechtenberg, 1995). As the disease progresses, an increased number of symptoms may emerge. The multiplicity of the overall symptoms associated with MS is indicated in Table 1.

Table 1: Frequency of related MS symptoms

Balance abnormalities	78%	Paraesthesiae	40%
Impaired sensation	71%	Giddiness	32%
Paraparesis	62%	Hemiparesis	18%
Micturation changes	62%	Facial palsy	15%
Optic neuritis	55%	Epilepsy	5%
Monoparesis	52%	Impotence	5%
Ataxia of limbs	45%	Hearing loss	4%
Diplopia	43%	Tic douloureaux	2%

Sourced from: Müller (1949:10)

The most frequently encountered symptom (from an otological point of view) was disturbances in balance (78 %), whereas hearing loss was a rare complaint associated with MS (4 %).

APPENDIX B

THE COURSE OF MULTIPLE SCLREROSIS SYMPTOMS

THE COURSE OF SYMPTOMS ASSOCIATED WITH MULTIPLE SCLEROSIS

The aim of Appendix B is to provide a description of the different courses that the disease can follow. Noseworthy et al. (2001) described four courses of MS:

- **The relapsing-remitting (RR) course:** Each flare-up (exacerbation or relapse) of a patient's symptoms is a sign that inflammation or demyelination is occurring. The site of demyelination in the CNS and the extent thereof determines the symptoms produced, for example: if demyelination occurs in the optic nerve, the patient experiences visual disturbances. When the patient enters a period free of evolving symptoms, he or she is said to be in remission. The recovery (or improvement) after each episode is complete (Lechtenberg, 1995). The relapses are severe and occur frequently. Following the first attack of the disease, relapses can occur after months or years. They involve either the re-emergence of old symptoms or the appearance of new deficits, or both.

- **The secondary progressive course (SP):** In some patients the course of the disease is initially RR in nature, but develops progressively. In this course of the disease the related symptoms fail to remit completely and deterioration becomes progressive.

- **The chronic progressive/primary progressive (PP) course:** One symptom after another appears with no apparent or significant respite from the disease. In this course of the disease, severe disability increases over time.

- **Benign course (B):** Some patients experience only a few episodes of abruptly appearing symptoms that resolve quickly and leave no permanent disabilities (Lechtenberg, 1995). Only after several years the disease will progress and lead to disability (Knight, 1992).

APPENDIX C

COVER LETTER, CONSENT FORM, GENERAL INSTRUCTIONS AND QUESTIONNAIRE

DEKBRIEF, TOESTEMMINGSVORM, ALGEMENE INSTRUKSIES EN VRAELYS

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

University of Pretoria

Pretoria 0002 Republic of South Africa Tel (012) 420-2357 / 420-2816 Fax (012) 420-3517 http://www.up.ac.za

Department of Communication Pathology
Speech, Voice and Hearing Clinic

November 2001

Dear Respondent,

I am currently studying towards a Masters degree in Audiology at the Department of Communication Pathology of the University of Pretoria. My field of interest is persons with Multiple Sclerosis, their hearing abilities and the testing thereof.

WHAT AM I INVESTIGATING?

- Multiple Sclerosis can have an effect on the auditory system, either from the ear to the brain, or only the auditory part of the brain. Through simple and advanced hearing tests this can be investigated.
- In addition, I will want to determine your subjective perception of your hearing abilities, and other related symptoms during the time that you have had MS.
- Many studies about hearing and the testing thereof have been performed overseas. However, a few studies involving MS (in general) have been performed in South-Africa. The information now obtained could be used to assist audiologists in evaluating an individual with MS more effectively.

WHAT WILL THIS INVOLVE?

- I will need you to fill in the questionnaire and post it back to me. If you meet the selection criteria that have been designed for the study, you will be informed telephonically. A date and time will be scheduled at your convenience for hearing tests.
- I will need to confirm some of your medical information with your neurologist.
- I will need you to come to the University of Pretoria (Hatfield), Department of Communication Pathology for your hearing to be tested. The testing will take

about two hours. The results will be given to you. Of course there will be no charge!

WHAT HAPPENS TO THE INFORMATION GATHERED IN THE STUDY?

- The researcher (myself), supervisor and co-supervisor involved in this project are qualified audiologists who will deal with all information in strict confidence.
- The information from the questionnaire and hearing tests will be statistically evaluated.
- You will remain anonymous when I report our findings.
- The findings of the study will be made available to you after its completion, if you so wish.

WHAT HAPPENS IF YOU DON'T MEET THE SELECTION CRITERIA?

- Unfortunately, you will not be able to undergo the hearing test.
- The information provided in the questionnaire will still be used in the study.
- You will be referred to an audiologist in your area if you are interested in undergoing hearing testing.

WHAT HAPPENS IF YOU CHANGE YOUR MIND DURING THE STUDY?

- You will be able to withdraw at any time.
- The study is completely voluntary.
- If you change your mind, any benefits that I have offered to you in terms of information will still be available.

WHAT IF THE RESULTS GENERATE A NEED FOR FURTHER TREATMENT?

You will be referred to an audiologist in your area for rehabilitation. Your results may be handed to him or her with your permission.

I wish to thank you in anticipation for your kind cooperation.

Yours sincerely

René Hornby
AUDIOLOGIST

Professor Hugo
SUPERVISOR AND HEAD OF
COMMUNICATION
PATHOLOGY DEPARTMENT

INFORMED CONSENT FORM

If you would like to participate in this study, please complete and sign the consent form, complete the questionnaire and return both the questionnaire and the form to me by 30 November 2001, or fax it to (012) 331-4469. If you have any questions, you may phone me at (012) 331-4469 (office hours) or 083 701 6618 (after hours).

I, _____, am willing to participate in the study. I hereby give permission that my medical history be provided to you by my neurologist.

Signature:_____ Date: _____

GENERAL INSTRUCTIONS

1. Instructions for the answering of questions are provided in italics at the end of each question. The appropriate answer must be marked with an "x" or be written in the space provided.

2. It would be appreciated if you could answer the questions as carefully as possible. The success of this questionnaire depends on the honesty and comprehensiveness of your answers.

3. The questionnaire consists of eight pages. Completion of the questionnaire should take about 15 minutes.

4. All information will be treated as strictly confidential and you will remain anonymous.

5. A stamped envelope is enclosed. Please send the questionnaire to me after completion. I would appreciate it reaching me by 30 November 2001 at the latest.

6. I will contact you telephonically for future testing.

7. Your time and cooperation are sincerely appreciated. Many thanks!

NOTE: The abbreviation MS that is used in the questionnaire stands for Multiple Sclerosis

---

QUESTIONNAIRE

Respondent number | For office use

V1 [ ][ ] 1-2

Instructions:
Mark the appropriate answer with X. Blank spaces must be written in.

SECTION A

1. Surname and names: _____

   _____

2. Postal address: _____

   _____

   Code: _____

3. Telephone number: (W) _____ (H):_____

   Cellular _____

4. Name of current neurologist(s)? Dr/Prof. _____

5. Where is/are he or she located? _____

6. Telephone number of neurologist?: _____

7. Date of birth: _____(day)_____(month) _____(year)

   Age: _____

   V2 [ ][ ] 3-4

8. Are you male or female?

MALE	1
FEMALE	2

   V3 [ ] 5

9. Were you born in South Africa?

YES	1
NO	2

   V4 [ ] 6

10. If not South African, how old were you on immigrating to South Africa?

    Age: _____

    V5 [ ][ ] 7-8

11. What is your race?

Asian	1
Black	2
White	3
Coloured	4

    V6 [ ] 9

SECTION B

12. When were you diagnosed with Multiple Sclerosis?

_____(year)

V7 [ ][ ][ ][ ] 10-13

13. At present, is your MS classified as ...?
(Please mark the appropriate block with X)

Benign multiple sclerosis	1
Relapsing/remitting MS	2
Secondary progressive MS	3
Primary progressive MS	4
Uncertain	5

V8 [ ] 14

14. When did you first notice symptoms, related to MS?

_____(year)

V9 [ ][ ][ ][ ] 15-18

15. Which of the following symptoms were some of your initial symptoms? (*You may mark more than one item.)*

"Abnormal sensations", for example: feelings of heat, cold, tingling, pins and needles, crawling, itching in hands/arms/legs	1	V10 [ ]	19
Visual disturbances	2	V11 [ ]	20
Heaviness or weakness in arms/trunk/legs	3	V12 [ ]	21
Pain in arms, legs and or trunk	4	V13 [ ]	22
Difficulty with hearing	5	V14 [ ]	23
Tinnitus (sounds/noise/buzzing in ears or head)	6	V15 [ ]	24
Vertigo (feeling of spinning or being drunk)	7	V16 [ ]	25
Bladder problems	8	V17 [ ]	26

OTHER SYMPTOMS:
(Specify)

_____ V18 [ ][ ] 27 – 28

_____ V19 [ ][ ] 29 – 30

_____ V20 [ ][ ] 31 – 32

_____ V21 [ ][ ] 33 – 34

_____ V22 [ ][ ] 35 – 36

SECTION C

19. Have you experienced any of the following?
(Please answer all questions)

	YES	NO			
Recurrent or chronic middle ear infections?	1	2	V38		57
Specify:					
Previous ear surgery?	1	2	V39		58
Specify:					
Accidents and/or injuries to ear and/or head?	1	2	V40		59
Specify:					
Exposure to high levels of noise e.g. military, mining, industrial, hobbies?	1	2	V41		60
Specify:					
(If you answered "yes") were/are hearing protectors used?	1	2	V42		61
Specify:					
Difficulty with hearing before the onset of MS?	1	2	V43		62
Specify:					
Is there a family history of hearing impairment?	1	2	V44		63
Specify:					

20. Are you currently aware of a "ringing" or "buzzing" sound or noise (tinnitus) in your ear(s) and/or head? *(Please mark one)*

YES (DAILY)	1	V45		64
SOMETIMES	2			
NO (NEVER)	3			

(If you answered "no", ignore Question 21)

21. Do you notice the "ringing" or "hissing" or other sound or noise (tinnitus) in your ... *(Mark one)*

HEAD	1	V46		65
BOTH EARS	2			
RIGHT EAR	3			
LEFT EAR	4			
UNSURE OF LOCATION	5			

22. Do you ever experience a feeling of **dizziness or lightheadedness?** *(Mark one)*

YES (MOST OF THE TIME)	1	V47		66
SOMETIMES	2			
NO (NEVER)	3			

PLEASE DESCRIBE:

_____	V48		67-68
_____	V49		69-70
_____	V50		71-72
_____	V51		73-74
_____	V52		75-76

23. Do you ever experience **a feeling of movement or spinning** of yourself or objects (vertigo)? *(Mark one)*

YES (DAILY)	1	V53		77
SOMETIMES	2			
NO (NEVER)	3			

SECTION D

24. *Mark the option which best describes your hearing in each ear with X.. If you use a hearing aid(s), please describe the way you hear without the hearing aid(s)*

	LEFT EAR	RIGHT EAR			
MY HEARING IS GOOD	1	1	V54		78
LITTLE TROUBLE HEARING	2	2	V55		79
LOTS OF TROUBLE HEARING	3	3			
I AM DEAF/CANNOT HEAR	4	4			

(If your hearing is "good in both ears", ignore Questions 25,26 and 27 and carry on with Question 28)

25. Was the onset of the hearing loss ...? *(Mark one)*

GRADUAL	1	V56		80
SUDDEN	2			
UNSURE	3			

26. When, for the first time, did you become aware of difficulty with hearing?

BEFORE YOUR INITIAL (FIRST) SYMPTOMS OF MS	1	V57		81
DURING THE TIME YOU EXPERIENCED SYMPTOMS OF MS	2	V58		82
ONLY AT A LATER STAGE OF MS	3	V59		83
OTHER (SPECIFY) _____	4	V60		84-85

27. Describe the nature of your hearing loss. Is it ...? *(Mark one)*

STABLE (REMAINS THE SAME)	1	V58		86
PROGRESSIVE (GETTING WORSE)	2			
FLUCTUATING (BETTER, WORSE, BETTER)	3			
UNSURE	4			

28. Have you been referred to an ear, nose and throat specialist, Audiologist or hearing-aid acoustican for a hearing test during the time of MS?

YES	1	V59		87
NO	2			

(If you answered "no", ignore Questions 29 and 30)

29. Did that hearing test indicate a hearing loss?

YES	1
NO	2

V60 [ ] 88

30. Are you currently using a hearing aid or hearing aids?

YES	1
NO	2

V61 [ ] 89

SECTION E

31. Do you experience any of the following hearing problems?
(Please describe the way you usually hear with both ears. If you use a hearing aid(s), please describe how you hear without the aid(s). Mark YES, SOMETIMES, or NO for each question. Do not skip a question.)

	YES	SOMETIMES	NO			
Have you noticed that people seem to mumble?	1	2	3	V62	[ ]	90
Do you find yourself asking people to repeat?	1	2	3	V63	[ ]	91
Do you hear words but don't **Understand** them?	1	2	3	V64	[ ]	92
Do you find it difficult to hear in the presence of background noise, e.g., parties or groups?	1	2	3	V65	[ ]	93
Do you have difficulty hearing when someone speaks to you from another room?	1	2	3	V66	[ ]	94
Do you have difficulty hearing when a speaker's face is not visible?	1	2	3	V67	[ ]	95
Have you been told that you have Missed the ringing of the telephone?	1	2	3	V68	[ ]	96
Do you need to turn up the volume of the TV and/or radio to understand clearly?	1	2	3	V69	[ ]	97
Do you find it difficult to hear while using the telephone?	1	2	3	V70	[ ]	98
Do your family and/or friends say you have a hearing problem?	1	2	3	V71	[ ]	99
Do you avoid social events because you have difficulty with hearing?	1	2	3	V72	[ ]	100
Do you experience difficulty localizing the direction of sound?	1	2	3	V73	[ ]	101

32. Do the above-mentioned hearing difficulties affect the quality of your life? *(Mark one)*

YES	1
NO	2
NOT APPLICABLE	3

V74 ☐ 102

33. Do you experience your **hearing problem(s) as** ...? *(Mark one answer only)*

One of the more significant problems of MS	1
Equal to the other problems of MS	2
One of the less significant problems of MS	3
Not applicable	4

V75 ☐ 103

34. Any other comments about your hearing and hearing problems?

_____ V76 ☐☐ 104-105

_____ V77 ☐☐ 106-107

_____ V78 ☐☐ 108-109

_____ V79 ☐☐ 110-111

_____ V80 ☐☐ 112-113

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November 2001

Beste Respondent

Ek is tans besig met my Meestersgraad in Oudiologie by die Departement Kommunikasiepatologie aan die Universiteit van Pretoria. Ek stel belang in persone met Veelvuldige Sklerose, hul gehoorvermoens en die toetsing daarvan.

WAT WORD ONDERSOEK?

- Veelvuldige Sklerose kan die gehoorsisteem affekteer, vanaf die binne-oor tot by die brein. Deur middel van eenvoudige en gesofistikeerde gehoortoetsing kan dit geëvalueer word.
- Ook wil ek graag u subjektiewe belewenis van u gehoorvermoëns en ander addisionele simptome wat u mag ondervind gedurende die tydperk wat u MS het, ondersoek.
- Verskeie studies aangaande gehoor en die toetsing daarvan is al oorsee uitgevoer, maar slegs enkele studies oor MS (in die algemeen) is al in Suid-Afrika uitgevoer. Die inligting wat deur middel van hierdie studie ingewin word, sal oudioloë kan help om persone met MS meer effektief te evalueer.

WAT BEHELS DIE STUDIE?

- U moet die vraelys invul en aan my terugstuur. Indien u voldoen aan die seleksie-kriteria wat vir die studie ontwikkel is, sal ek u telefonies in kennis stel. 'n Datum en tyd wat vir u gerieflik is, sal vir gehoortoetsing geskeduleer word.
- Sommige van u mediese inligting sal deur u neuroloog bevestig moet word.

- U moet na die Universiteit van Pretoria (Hatfield), Departement Kommunikasie-patologie, kom vir die gehoortoetse. Die toetse sal ongeveer twee ure duur. Die resultate daarvan sal aan u verduidelik word. Dit is natuurlik gratis!

WAT GEBEUR MET DIE INLIGTING WAT VANUIT DIE STUDIE VEKRY WORD?

- Die navorser (ekself), leier en medeleier is almal gekwalifiseerde oudioloë wat alle inligting as vertroulik sal hanteer.
- Die inligting wat uit die vraelys en gehoortoetsresultate verkry is, word statisties verwerk.
- U bly anoniem wanneer resultate in verslagformaat uiteengesit word.
- Na die voltooiing van die studie sal die bevindinge aan u beskikbaar gestel word.

WAT GEBEUR INDIEN U NIE AAN DIE SELEKSIEKRITERIA VOLDOEN NIE?

- Ongelukkig sal u nie die gehoortoetse kan ondergaan nie.
- Die inligting wat u in die vraelys verstrek het, kan steeds in die studie gebruik word.
- As u gehoortoetse wil laat ondergaan, kan ek u na 'n oudioloog in u omgewing verwys.

WAT GEBEUR INDIEN U GEDURENDE DIE STUDIE VAN PLAN VERANDER?

- U mag enige tyd onttrek.
- Die studie is heeltemal vrywillig.
- Indien u besluit om nie meer betrokke te wees nie, sal al die voordele wat ek in terme van inligting belowe het, steeds geld.

WAT GEBEUR INDIEN DIE UITSLAG VAN DIE GEHOORTOETSE AANTOON DAT VERDERE OUDIOLOGIESE BEHANDELING NOODSAAKLIK IS?

- U sal na 'n oudioloog in u omgewing verwys word vir verdere rehabilitasie. Die uislag van u gehoortoetse kan met u toestemming aan hom of haar verskaf word.

By voorbaat dankie vir u samewerking.

Vriendelike groete

René Hornby
OUDIOLOOG

Professor Hugo
STUDIELEIER EN
DEPARTEMENTSHOOF VAN
KOMMUNIKASIEPATOLOGIE

TOESTEMMINGSVORM

Vul asseblief die toestemmingsvorm in indien u aan die studie wil deelneem en stuur dit voor 30 November 2001 saam met die ingevulde vraelys terug aan my, of faks dit aan (012) 331-4469. As u enige vrae het, kan u my gerus skakel by (012) 331-4469 (kantoorure), of by 083 701 6618 (na-ure)

Ek, _____, is bereid om aan die studie deel te neem. Hiermee gee ek toestemming dat my neuroloog my mediese geskiedenis aan u verkaf.

Handtekening:_____ Datum: _____

ALGEMENE INSTRUKSIES

1. Instruksies vir die beantwoording van vrae word aan die einde van elke vraag in kursief aangedui. Die toepaslike antwoord moet met 'n "X" gemerk word, of die spasie wat verskaf word, moet ingevul word.

2. Ek sal dit waardeer as u die vrae so noukeurig moontlik beantwoord. Die sukses van die vraelys hang van die eerlikheid en volledigheid van u antwoorde af.

3. Die vraelys bestaan uit agt bladsye en behoort ongeveer 15 minute te neem om in te vul.

4. Alle inligting sal as streng vertroulik hanteer word en u sal anoniem bly.

5. 'n Gefrankeerde koevert is hierby ingesluit. Stuur die vraelys asseblief terug nadat u dit ingevul het. Ek sal dit waardeer indien ek dit teen 30 November 2001 kan ontvang vir die verwerking daarvan.

6. Ek sal telefonies met u in verbinding tree aangaande toekomstige toetsing.

7. U tyd en samewerking word opreg waardeer. Baie dankie!

NEEM KENNIS: Die afkorting MS wat in die vraelys gebruik word, staan vir Multiple Sclerosis of Veelvuldige Sklerose.

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UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

VRAELYS

Respondentnommer | Vir kantoorgebruik

V1 [ ][ ] 1-2

Instruksies:
Merk die toepaslike antwoord met X. Oop spasies moet ingevul word.

AFDELING A

1. Van en voornaam: _____

_____

2. Posadres: _____

_____

Kode: _____

3. Telefoonnommer: (W) _____ (H):_____

Sellulêr _____

4. Wie is tans u neuroloog/? Dr/Prof _____

5. Waar praktiseer hy of sy? _____

6. Neuroloog se telefoonnommer?: _____

7. Geboortedatum: _____(dag)_____(maand) _____(jaar)

Ouderdom: _____

V2 [ ][ ] 3-4

8. Is u manlik of vroulik?

MANLIK	1
VROULIK	2

V3 [ ] 5

9. Is u in Suid-Afrika gebore?

JA	1
NEE	2

V4 [ ] 6

10. Indien u nie in Suid-Afrika gebore is nie, hoe oud was u tydens immigrasie na Suid-Afrika?

Ouderdom: _____

V5 [ ][ ] 7-8

11. Aan watter rassegroep behoort u?

Indiër	1
Swart	2
Blank	3
Kleurling	4

V6 [ ] 9

AFDELING B

12. Wanneer is u gediagnoseer met MS?

_____(jaar)

V7 [ ][ ][ ][ ] 10-13

13. In watter kategorie is u MS tans geklassifiseer?
(Merk die toepaslike blokkie asseblief met X)

Benigne MS	1
Relaps/remitting MS	2
Sekondêre progressiewe	3
Primêre progressiewe MS	4
Onseker	5

V8 [ ] 14

14. Wanneer het u vir die eerste keer simptome van MS opgemerk?

_____(jaar)

V9 [ ][ ][ ][ ] 15-18

15. Watter van die volgende geassosieerde simptome van MS het u die eerste opgemerk? *(U mag meer as een merk.)*

"Abnormale sensasies" bv. gevoel van hitte, koue, tintelling, naalde en spelde, beweging, jukkerigheid in arms/bene/bolyf	1	V10	[ ]	19
Sigprobleme (oogprobleme)	2	V11	[ ]	20
Swaarheid of swakheid van die arms/bolyf/bene	3	V12	[ ]	21
Pyn in die arms/bolyf/bene	4	V13	[ ]	22
Gehoorprobleme	5	V14	[ ]	23
Tinnitus (suising/fluitgeluid/klank in ore of kop)	6	V15	[ ]	24
Vertigo (gevoel van draaiing en/of dronk in kop	7	V16	[ ]	25
Blaasprobleme	8	V17	[ ]	26

ANDER SIMPTOME:
(*Spesifiseer*)

_____	V18	[ ][ ]	27 – 28
_____	V19	[ ][ ]	29 – 30
_____	V20	[ ][ ]	31 – 32
_____	V21	[ ][ ]	33 - 34
_____	V22	[ ][ ]	35- 36

16. Gebruik u tans enige medikasie (behalwe vitamines)?

JA	1
NEE	2

V23 ☐ 37

(Indien u "nee" geantwoord het, ignoreer Vraag 17 en gaan aan met Vraag 18)

17. Naam van die medikasie wat **tans** gebruik word:

NAAM VAN MEDIKASIE	WAARVOOR GEBRUIK WORD		
		V24 ☐☐	38 – 39
		V25 ☐☐	40 – 41
		V26 ☐☐	42 – 43
		V27 ☐☐	44 – 45
		V28 ☐☐	46 – 47

18. Het u 'n familielid wat ook met MS gediagnoseer is?

JA	1
NEE	2

V29 ☐ 48

Indien u "ja" geantwoord het, wat is die verwantskap?
(Merk asseblief die toepaslike blokkie)

Ouer	1	V30 ☐	49
Grootouer	2	V31 ☐	50
Broer	3	V32 ☐	51
Suster	4	V33 ☐	52
Oom	5	V34 ☐	53
Tannie	6	V35 ☐	54
Neef/Niggie	7	V36 ☐	55
Kind	8	V37 ☐	56

AFDELING C

19. Watter van die volgende het u al ondervind?
(Alle vrae moet beantwoord word)

	JA	NEE			
Gereelde of kroniese middeloorinfeksies?	1	2	V38		57
Spesifiseer:					
Enige oorchirurgie?	1	2	V39		58
Spesifiseer:					
Ongelukke en/of beserings aan kop en/of ore?	1	2	V40		59
Spesifiseer:					
Blootstelling aan hoë geraasvlakke, bv. militêre, industriële of stokperdjiegeraas?	1	2	V41		60
Spesifiseer:					
Indien u "ja" geantwoord het op vorige vraag, het u gehoorbeskermers gedra?	1	2	V42		61
Spesifiseer:					
Enige probleme met gehoor voor die aanvang van MS?	1	2	V43		62
Spesifiseer:					
Is daar 'n familiegeskiedenis van gehoorprobleme?	1	2	V44		63
Spesifiseer:					

20. Is u tans bewus van 'n "suising" of fluitgeluid" of klank (tinnitus) in u oor/ore of kop?

JA (DAAGLIKS)	1	V45		64
SOMTYDS	2			
NEE (NOOIT)	3			

(Indien u "nee" geantwoord het, ignoreer Vraag 21)

21. Is hierdie "suising" of "fluitgeluid" of ander geluid in u ...?
(Merk een)

KOP	1	V46		65
BEIDE ORE	2			
REGTEROOR	3			
LINKEROOR	4			
ONSEKER VAN PLEK	5			

22. Ondervind u ooit **duiseligheid** of 'n gevoel van **lighoofdigheid?**

JA (DAAGLIKS)	1	V47		66
SOMTYDS	2			
NEE (NOOIT)	3			

BESKRYF ASSEBLIEF:

_____	V48		67-68
_____	V49		69-70
_____	V50		71-72
_____	V51		73-74
_____	V52		75-76

23. Ondervind u 'n gevoel van **beweging of draaiing** van uself of ander voorwerpe (vertigo)?

JA (DAAGLIKS)	1	V53		77
SOMTYDS	2			
NEE (NOOIT)	3			

AFDELING D

24. *Merk die opsie wat u gehoorvermoë in elke oor die beste beskryf met X. Indien u 'n gehoorapparaat of –apparate dra, beskryf asseblief hoe u daarsonder hoor.*

	LINKEROOR	REGTEROOR			
MY GEHOOR IS GOED	1	2	V54		78
EK HET GERINGE GEHOORPROBLEME	1	2	V55		79
EK HET BAIE GEHOORPROBLEME	1	2			
EK IS DOOF/KAN NIE HOOR NIE	1	2			

(Indien u "gehoor goed is in beide ore", ignoreer Vrae 25, 26 en 27 en gaan voort met Vraag 28)

25. Hoe was die aanvang van u gehoorverlies? *(Merk een)*

GELEIDELIK	1	V56		80
SKIELIK	2			
ONSEKER	3			

26. Wanneer was u vir die eerste keer bewus van probleme met gehoor?

VOOR U EERSTE MS-SIMPTOME	1	V57		81
SAAM MET U EERSTE MS-SIMPTOME	2	V58		82
EERS IN 'N LATERE STADIUM VAN U MS	3	V59		83
ANDER (SPESIFISEER)_____	4	V60		84-85

27. Beskryf u gehoorvermoëns. Dit ... *(Merk een)*

BLY DIESELFDE	1	V58		86
VERSLEG PROGRESSIEF (WORD SWAKKER)	2			
FLUKTUEER (VERBETER, VERSLEG, VERBETER)	3			
ONSEKER	4			

28. Is u al verwys na 'n oor-, neus- en keelspesialis, oudioloog of gehoorapparaathandelaar vir gehoortoetsing in die tydperk wat u MS het?

JA	1	V59		87
NEE	2			

(Indien u "nee" geantwoord het, ignoreer Vraag 29 en 30)

29. Is 'n gehoorverlies geïdentifiseer tydens dié gehoortoetsing?

JA	1
NEE	2

V60 [ ] 88

30. Dra u tans 'n gehoorapparaat of gehoorapparate?

JA	1
NEE	2

V61 [ ] 89

AFDELING E

31. Ondervind u enige van die volgende gehoorprobleme?
(Dui aan hoe u gewoonlik met beide ore hoor. Indien u 'n gehoorapparaat dra, dui aan hoe u daarsonder hoor. Merk JA, SOMTYDS of NEE vir elke vraag. Beantwoord al die vrae).

	JA	SOMTYDS	NEE			
Kom dit vir u voor asof mense mompel?	1	2	3	V62	[ ]	90
Moet u 'n spreker vra om te herhaal wat hy/sy gesê het?	1	2	3	V63	[ ]	91
Kan u woorde hoor, maar dit nie **verstaan** nie?	1	2	3	V64	[ ]	92
Ondervind u probleme om te hoor in die teenwoordigheid van agtergrondlawaai, bv. partytjies of tussen groepe.	1	2	3	V65	[ ]	93
Het u probleme om te hoor wanneer iemand vanuit 'n ander vertrek met u praat?	1	2	3	V66	[ ]	94
Ondervind u probleme om te hoor as die speker se gesig nie sigbaar is nie?	1	2	3	V67	[ ]	95
Het u al die lui van die telefoon nie gehoor nie?	1	2	3	V68	[ ]	96
Moet u die volume van die TV of radio harder stel om goed te kan hoor?	1	2	3	V69	[ ]	97
Ondervind u probleme om 'n gesprek te volg/te hoor oor die telefoon?	1	2	3	V70	[ ]	98
Is u familie en/of vriende van mening dat u gehoorprobleme het?	1	2	3	V71	[ ]	99
Vermy u sosiale byeenkomste a.g.v. probleme met gehoor?	1	2	3	V72	[ ]	100
Is dit vir u moeilik om te bepaal uit watter rigting klank kom?	1	2	3	V73	[ ]	101

32. Affekteer hierdie gehoorprobleme u lewenskwaliteit? *(Merk een)*

JA	1
NEE	2
NIE VAN TOEPASSING NIE	3

V74 [ ] 102

33. Ervaar u, u **gehoorprobleem of –probleme** as ...? *(Merk een)*

Een van die meer betekenisvolle probleme van MS	1	V75		103
Gelykstaande aan die ander probleme van MS	2			
Een van die minder betekenisvolle probleme van MS	3			
Nie van toepassing nie	4			

34. Enige ander kommentaar aangaande u gehoor of gehoorprobleme?

_____	V76		104-105
_____	V77		106-107
_____	V78		108-109
_____	V79		110-111
_____	V80		112-113