THE CLINICAL VALUE OF AUDITORY STEADY STATE RESPONSES IN THE AUDIOLOGICAL ASSESSMENT OF PSEUDOHYPACUSIC WORKERS WITH NOISE-INDUCED HEARING LOSS IN THE SOUTH AFRICAN MINING INDUSTRY

by

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The real secret of success is enthusiasm.
Walter Chrysler

Enthusiasm releases the drive to carry you over obstacles and adds significance to all you do.
Norman Vincent Peale

If you can give your son or daughter only one gift, let it be enthusiasm.
Bruce Barton

You can do anything if you have enthusiasm. Enthusiasm is the yeast that makes your hopes rise to the stars. With it, there is accomplishment. Without it there are only alibis.
Henry Ford

Success is the ability to go from failure to failure without losing your enthusiasm.
Winston Churchill

Knowledge is power, but enthusiasm pulls the switch.
Ivern Ball

2 Kor. 1:3
Aan God, die Vader van ons Here Jesus Christus, kom al die lof toe! Hy is die Vader wat Hom ontferm en die God wat in elke omstandigheid moed gee

To my parents, Faan and Elsabe Alberts,

my husband, Dr F.D. de Koker, and

my four children, Derek, Elsabe, Stefan and Lize.

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List of abbreviations

A$	Australian dollar
ABR	Auditory brainstem response
AEP	auditory evoked potential
AM	amplitude modulated
AP	action potential
AR	acoustic reflex
ASSR	Auditory steady state response
AIDS	acquired immune deficiency syndrome
CER	cortical evoked responses
CERA	cortical evoked response audiometry
CNS	central nervous system
COIDA	The compensation of Occupational injuries and diseases Act
CF	carrier frequency
CM	cochlear microphonic
dB	decibel
EAM	external auditory meatus
EcochG	electrocochleogram
EEG	electro encephalogram
ENT	Ear- Nose- and Throat specialist
EP	electrophysiological tests
ERP	event related potential
f	frequency
FM	frequency modulation
FFT	fast fourier transform
GB	giga byte
GGG	geraas-geïnduseerde gehoorverlies
HIV	human immunodeficiency virus
HL	hearing level
HTL	hearing threshold level
Hz	Hertz
IBM	Internationa lbusiness machines
kHz	kilohertz
L	left
LLR	late latency response
MASTER	Multiple auditory steady state response system
MB	mega byte

MF	multiple frequency
MF-ASSR	Multiple frequency auditory steady state response
mg	milligram
MLR	middle latency response
MM	multi-modulation
mg	milligram
ms	millisecond
n	number
NIHL	noise-induced hearing loss
OAE	oto-acoustic emission
OHC	occupational health centre
OMP	occupational medical practitioner
OSR	ouditiewe standhoudende response
P	probility value
PC^2	phase coherence squared
PD	permanent disability
Ps	pseudohypacusis
PT	pure-tone
PTA	pure-tone average
LLR	late latency response
R	rand (South African currency)
RAM	random access memory
RMA	Rand Mutual Assurance
RSA	Republic of South Africa
SD	standard deviation
SIMRAC	Safety in mines research advisory committee
SF	Single frequency
SF-ASSR	single frequency steady state response
SNHL	sensory-neural hearing loss
SP	summating potential
SPAR	sensitivity prediction with the acoustic reflex
SRT	speech reception threshold
SSEP	steady state evoked potential
SVR	slow vertical response
USB	universal serial bus
USA	United States of America
µV	microvolt
WCC	Workmen's Compensation Commissioner

Title : The clinical value of auditory steady state responses in the audiological assessment of pseudohypacusic workers with noise-induced hearing loss in the South African mining industry

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SUMMARY

Large numbers of South African mine workers incur noise-induced hearing loss. The prevalence of noise-induced hearing loss is such that its financial implications for the industry are significant. This situation is often further compounded by an exaggeration of their hearing loss by some workers in an attempt to obtain compensation. Questionable cases must be re-assessed, increasing the cost of evaluations and the number of unproductive shifts.

The inability to obtain true pure-tone thresholds in unco-operative workers leads to ineffectiveness in and frustration for audiologists and occupational health centres because they are not delivering an accountable service to the mining company and individual workers. The failure to obtain pure-tone thresholds may also lead to deserving workers not receiving compensation, and sudden hearing loss not being diagnosed. Workers unfit for their present occupations can also be further exposed to noise.

Current audiological procedures can identify instances of exaggerated hearing loss (pseudohypacusis), but do not quantify the extent of exaggeration.

Traditional testing techniques require patient co-operation and, hence, are insufficient to resolve cases where patient co-operation is not forthcoming.

As a result this study was undertaken to determine the value of auditory steady state responses (ASSRs) as a means of estimating the pure-tone thresholds of noise-exposed workers. ASSRs need no response from the patient, and the electrical responses to the presented sound are measured by means of a real-time statistical analysis of the samples, using a computer, thereby offering real objectivity.

The following research question was addressed: “What is the clinical value of ASSRs in the audiological assessment of pseudohypacusic workers with noise-induced hearing loss?”

An experimental study was conducted, where different protocols and types of equipment used in the testing of ASSRs were evaluated in a group of mine workers with noise-induced hearing loss (n=81). The influence of sedation on the threshold estimation was also evaluated. The proven best protocol was finally evaluated in a pseudohypacusic group of workers (n=29).

The study indicates that ASSRs are a valid and accurate alternative to pure-tone testing in populations with noise-induced hearing loss. The test can serve as a once-off test procedure for an unco-operative client. The mean threshold estimates of ASSRs never differed more than 10 dB from the mean pure-tone thresholds. The test procedure was accurate throughout the severity range of hearing loss, and age did not influence the reliability of the threshold estimates.

Single-frequency techniques were found to be the technique of choice in this population and it is recommended that the 40 Hz response is employed as a modulation frequency. Sedation did not have any effect on the length and the sensitivity of the procedure, and is thus not advocated if co-operation can be obtained. The length of the procedure is estimated at 60 minutes.

Finally, this study has contributed to the validation of the technique (previous research was limited). As a result of this study, the implementation of this procedure in mines' audiological centres is advocated since it has been proven to be of clinical value.

Titel	:	Die kliniese waarde van ouditiewe standhoudende response in die oudiologiese evaluasie van werkers met funksionele en geraas-geïnduseerde gehoorverlies in die Suid-Afrikaanse mynbedryf
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OPSOMMING

Mynwerkers doen in die loop van ondergrondse werk geraas-geïnduseerde gehoorverlies (GGG) op. Die hoë voorkoms van GGG het finansiële implikasies vir die mynbedryf. Hierdie finansiële implikasies word vererger indien werkers hulle gehoorverlies oordryf om meer vergoeding te kry. Werkers by wie daar nie akkurate gehoordrempels vasgestel kon word nie, moet herevalueer word en so eskaleer kostes verder.

Dit is verstaanbaar dat 'n onvermoë om drempels by 'n werker te bepaal tot frustrasie en ’n gevoel van oneffektiwiteit bydra, wat die oudioloog en ook die beroepsgesondheidsklinieke direk raak. Die oudioloog is immers daarvoor verantwoordelik om ’n toerekenbare diens aan die werkgewer en individuele werkers te lewer. ’n Onvermoë om gehoordrempels te bepaal het ook tot gevolg dat werkers met GGG nie die kompensasie wat hulle toekom kry nie en ’n skielike gehoorverlies kan ongediagnoseerd bly. Werkers met ernstige

gehoorverlies, word by die gebrek aan akkurate gehoordrempels, verder aan skadelike geraas blootgestel.

Huidige gehoortoetse kan funksionele gehoorverlies identifiseer, maar kan dit nie kwantifiseer nie. Lug- en beengeleidingstoetse word internasionaal as die norm aanvaar, maar vereis samewerking van die pasiënt.

'n Studie is gevolglik onderneem om die waarde van ouditiewe stand-houdende response (OSR) in die oudiologiese evaluasie van werkers met GGG te bepaal en die vraag is spesifiek of die OSR akkurate drempels, in hierdie volwasse bevolking, kan bepaal. Die veronderstelling is dat ouditief ontlokte potensiale objektief is en dat geen respons van die pasiënt verwag word nie. OSR het ook 'n verdere dimensie in objektiwiteit waar die elektriese response, met statistiese ontleding, deur 'n rekenaar gemeet word.

Die navorsingsvraag wat dus aangespreek word is: "Wat is die kliniese waarde van OSR in die oudiologiese evaluasie van mynwerkers met funksionele komponente tot GGG?"

'n Eksperimentele studie het gevolg waar verskillende toetsprotokolle en apparatuur gebruik is in die evaluasie van mynwerkers met GGG (n=81). Die invloed wat sedasie op die drempelbepalings gehad het, is ook evalueer. Die beste protokol is vervolgens ook in 'n groep mynwerkers (n=29) met funksionele gehoorverlies getoets.

Die studie het bewys dat OSR 'n geldige en akkurate alternatiewe toets vir suiwertoonoudiometrie, in 'n volwasse bevolking met GGG is. Die toets kan as 'n enkeltoets funksioneer indien die pasiënt sawewerking weerhou. Die gemiddelde drempelskattings van OSR het nooit meer as 10 dB van die suiwertoondrempels verskil nie. Skattings van gehoordrempels was moontlik by alle grade en erns van gehoorverlies. Verder het die ouderdom van werkers nie 'n invloed op die akkuraatheid van die drempelskattings gehad nie.

Daar word aanbeveel dat die enkelfrekwensie-tegniek (monoraal) en spesifiek die 40 Hz respons gebruik word. Sedasie het geen invloed op die akkuraatheid van die drempelskattings en die toetstyd gehad nie en daarom word sedasie nie aanbeveel as passiewe samewerking van die pasiënt teenwoordig is nie. Die prosedure het ongeveer 60 minute geneem.

Die huidige studie het verder bygedra tot die beperkte kliniese validasie wat nog ten opsigte van OSR bestaan. Op grond van hierdie studie word die implementering van hierdie tegniek in die Suid-Afrikaanse mynwese aanbeveel, aangesien die kliniese waarde daarvan bewys is.

CHAPTER 1

INTRODUCTION

AIM

To introduce a study of auditory steady state responses in pseudohypacusic workers with noise-induced hearing loss in the South African mining industry, indicating the rationale for the study, the problem statement, proposed solutions, clarifying terminology and providing an outline of the study.

1.1 BACKGROUND

Large numbers of South African mine workers incur noise-induced hearing loss (NIHL), which is recognised as a compensable disease by the Compensation for Occupational Injuries and Diseases Act, (COIDA), No 130 of 1993. The prevalence of noise-induced hearing loss, is so high that the financial implications for the industry are significant, threatening the viability of marginal operations and eroding the profitability of larger companies. The impact of noise-induced hearing loss on workers' quality of life and their ability to earn a living is a matter of even greater concern, as the disease has socio-economic implications for the entire country and for the Southern African region as a whole (Franz, 2003). The financial impact of noise-induced hearing loss is often compounded by the exaggeration of hearing loss by some workers, in attempts to obtain compensation (De Koker, 2003).

Audiologists who are consulting in the mining industry are tasked with quantifying the impact of noise on workers' hearing, not only for compensation purposes, but also as a means of determining workers' fitness for work and evaluating employers' hearing conservation programmes (De Koker, 2003).

The audiological procedures currently used in the South African mining industry can identify* instances of exaggerated hearing loss (pseudohypacusis), but most audiological procedures cannot quantify the extent of any exaggeration (Roeser, Valente & Hosford-Dunn, 2000b; Martin, 1994). This study was therefore undertaken to determine the value of auditory steady state responses (ASSR) as a means of accurately estimating the true hearing thresholds of noise-exposed workers, to conclude diagnostic procedures and to enable appropriate recommendations regarding rehabilitation and/or compensation to be made.

1.2 RATIONALE

Most adults examined by audiologists for complaints about hearing loss have genuine disorders of the auditory mechanism. The audiologist must establish (among other tasks) the type and extent of hearing loss in order to determine the most appropriate course of action. Some options are rehabilitation (Stach, 1998), re-allocation or, in extreme cases, compensation and/or job termination (De Koker, 2003).

Unfortunately, some patients are not entirely co-operative during audiological procedures. This lack of co-operation can be due to several reasons, including possible misunderstanding of test procedures or their purpose, physical or psychological disorders, or the intention deliberately to misrepresent their hearing thresholds (Martin, 1994). Qiu *et al*. (1998) are of the opinion that such a lack of co-operation can be unconscious (psychogenic) or deliberate (malingering). The term "pseudohypacusis", (from "*pseudo"*, meaning "false"/ or "less-than-true", and "*hypacusis"*, meaning "hearing loss", is generally applied for cases of malingering (Rintelmann, Schwan & Blakley, 1991; Roeser, Valente & Hosford-Dunn, 2000).

*According to Stach (1998) audiological evaluation involve the determination of both the **type** and the extent or **degree** of hearing loss

In a review of literature on pseudohypacusis, Rintelmann *et al. (*1991) have found that the highest prevalence of the condition of pseudohypacusis has been noted among adult populations in which reporting hearing loss can result in monetary compensation. In the South African mining industry, the practice of paying compensation for noise-induced hearing loss is well documented (RMA guidelines, 2003; Franz, 2003; Franz & Phillips, 2001). Furthermore, it is well known that the prevalence of compensable noise-induced hearing loss is greater in the mining industry than in most other industries, largely because of the use of noisy machinery in confined and highly reverberant underground workplaces (Franz & Phillips, 2001). The labour-intensive methods used in many South African mines, particularly in conventional gold and platinum operations, where workforces are large, greatly increase the risk of noise-induced hearing loss (Franz & Phillips, 2001).

Recent experience with noise-induced hearing loss in the mining industry has shown that between 12 and 14 per cent of claims for all forms of disease and injury have been for noise-induced hearing loss. These 12 per cent of claims have accounted for nearly 40 per cent of compensation paid out (Begley, 2002). The above numbers indicate that noise-induced hearing loss is costing the industry a great deal more than would be expected in view of its prevalence in comparison to that of other occupational diseases. Noise-induced hearing loss claims settled by Rand Mutual Assurance, the underwriters of compensable risks for nearly 80 per cent of the local mining workforce, have come to between R76m and R110m since 1998 (Begley, 2003). If it is assumed that claims from the 22 per cent of mine workers who are otherwise insured (for example, by the Workmen's Compensation Commissioner) are proportionally similar, settlements for noise-induced hearing loss, industry-wide, can be estimated at between R98m and R142m since 1998. These amounts are undeniably substantial and they still fail to include the cost of repeat assessments, specialist referrals and transport arrangements. Nor do they include time off work and lost production. It must therefore be concluded that noise-induced hearing loss risks impose a significant financial and human resources burden on individual mining

operations and on the entire industry. They pose a threat to sustainability and create a potential for socio-economic impact that a developing country can ill afford (Franz, 2003).

Recent evidence indicates that thousands of workers (14 per cent of the total workforce of 300 000) have incurred noise-induced hearing loss in South African mines and are therefore entitled to compensation (Franz & Phillips, 2001). However, the experience of audiologists working in the mining industry suggests that there are significant numbers of claimants who exaggerate the existing hearing loss that they do experience, probably in an attempt to qualify for compensation or increase their settlement amounts (Franz, 2003).

Franz and Phillips (2001) claim that audiologists consulting in mines' Occupational Health Departments universally cite malingering, or pseudohypacusis, as the greatest impediment to an assessment of the true hearing status of patients referred to them. Over a three-month period in 2002, De Koker (2003) found clear indications of pseudohypacusis in 32 per cent of the 160 cases referred to her for audiological assessment. In these cases, the diagnosis of pseudohypacusis was based on discrepancies of more than 15 dB between the thresholds recorded during two pure-tone tests, in accordance with the criterion proposed by Rintelmann *et al*. (1991).

Rickards, de Vidi and McMahon (1996) have examined the financial impact of pseudohypacusis, citing Australian studies that report the incidence of pseudohypacusis to be between nine and 30 per cent among workers tested for compensation purposes. The same authors found that individual workers exaggerated their hearing loss by 12,2 per cent, on average, concluding that undetected exaggeration of hearing loss can lead to substantial increases in compensation payouts and, hence, in employers' costs for insuring their companies against the risk of noise-induced hearing loss. Rickards and De Vidi (1995) estimate that overcompensation to an average amount per claim of A$ 7 357, amounting to A$ 12m per year, is awarded to workers with exaggerated hearing loss in Australia. The South African mining industry, with

its much larger workforce and greater pressures on profitability (Franz, 2003) can ill afford such a waste of financial resources.

Pseudohypacusis also has a further financial impact, in that current audiological procedures rely on workers' co-operation to determine hearing thresholds. Consequently, questionable cases must be re-assessed several times by the consulting audiologists and Ear-, Nose-, and Throat (ENT) specialists (RMA guidelines, 2003). Such repeated testing increases the cost of evaluation and the number of unproductive shifts.

Diagnostic hearing evaluations employ mainly pure-tone air- and bone techniques, combined with speech discrimination testing, in accordance with the Workmen's Compensation Commissioner's (1995) Internal Instruction No 168. Although these procedures are regarded internationally as the gold standard for threshold determination, they require patient co-operation and, hence, are insufficient to resolve cases where such co-operation is not forthcoming (De Koker, 2003). The discussion above indicates that there is a need for reliable means of identifying pseudohypacusis, and of accurately recording noise-exposed workers' true hearing thresholds.

Martin (2000, p.594) argues that, in the majority of cases, it is not difficult to detect pseudohypacusis, but that "the more challenging responsibility of the audiologist is to determine the patient's organic thresholds of hearing". Several indicators of pseudohypacusis and special qualitative tests have been developed bearing in mind a pseudohypacusic population (Roeser, Valente & Hosford-Dunn, 2000; Martin, 1994). Qualitative tests have come and gone, and some have even become obsolete (Martin, 2000), because of the necessity for this much sought-after procedure to provide true hearing thresholds, and not only to identify pseudohypacusis as present.

The introduction of electrophysiological tests is the latest development in Audiology as a clinical science (Hall, 2000; Roeser *et al.,* 2000b): Immittance measures developed in the 1970s, auditory brainstem response testing in the 1980s and oto acoustic emissions in the last decade of the 20th century

(Hall, 2000). These audiological procedures differ from earlier tests primarily in that no voluntary response indicating "hearing" is required from the patient (Schmulian, 2002). Hall (1992) specifically advocates the use of electrophysiological tests as an objective means of determining auditory sensitivity. Electrophysiological tests have also been seen as the answer in difficult-to-test populations (Schmulian, 2002), of which pseudohypacusic mine workers are one example. In this regard, it is true that: "for measures of true thresholds our profession has tended to turn to electrophysiological procedures" (Martin, 2000, p.592). However, in this regard, one must remember that electrophysiological tests are not tests of hearing, *per se*, (*) but that they do, fortunately, have the ability to predict auditory thresholds (Sininger & Cone-Wesson, 1994).

In the South African mining industry, the current prescribed procedure in cases where reliable thresholds cannot be obtained is to retest the worker involved after six months (RMA guidelines, 2003). If accurate thresholds are still not obtained, an auditory brain stem response test (ABR) must be done (RMA guidelines, 2003). The electrophysiological test generally used in pseudohypacusic populations in the South African mining industry has thus been the ABR.

The ABR test measures far field evoked potentials by means of electrodes on the scalp of the patient, thereby endeavouring to estimate hearing thresholds. Electrical activity is measured specifically sub-cortically, and only up to brainstem level. ABR tests measure transient responses elicited by brief acoustic stimuli (Swanepoel, 2001). The most widely used stimulus is a broad band click, which stimulates a large portion of the basilar membrane, giving an indication of hearing thresholds in a range between 2 000 and 4 000 Hz (Schmulian, 2002).

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* Electrophysiological procedures, and particularly the auditory brain stem response, examine only a limited portion of the auditory system. The presence of an ABR indicates that synchronous neural firing is present only up to the level of the midbrain. Thus, the processing of sound is not measured at the cortical level. Similarly, the absence of an ABR does not prove that peripheral hearing loss exists, since disorders of the brainstem may obliterate an ABR, even though the peripheral auditory system is normal. A conventional hearing test relies, in the final instance, on a conscious behavioural response (Weber, 1994).

The limitation to being able to obtain threshold information only at 2 000 to 4 000 Hz has led to the development of additional (novel) stimuli, including tone bursts, filtered clicks and masking techniques, to obtain more frequency-specific information (Hood, 1998). The key to frequency specificity during ABR testing lies in the type of signal used (Halliday, 1993). Tone bursts are used to give low frequency information (Swanepoel, 2001), while masking techniques have to eliminate the effects of unwanted high frequency energy in gradual stimulus onset techniques (Weber, 1994). It has been found that pure tones cannot elicit sufficient neural synchrony for ABR testing (Goldstein & Aldrich, 1999).

Unfortunately, however, it seems that ABR testing in the mining industry has not supplied a final and satisfying solution to the increasing phenomenon of pseudohypacusis amongst mine workers. Weber (1994) and Gorga (1999) have pointed out the practical fact that the time needed to obtain a single ABR threshold for each ear exceeds 30 minutes, making full audiograms impractical. Furthermore, compensation assessments require frequency-specific information at five frequencies in each ear, namely at the following frequencies: 500, 1 000, 2 000, 3 000 and 4 000 Hz (Workmen's Compensation Commissioner, 1995). Because of the limitations inherent in the procedure, it is clear that the ABR cannot be used for compensation purposes. The high cost of instrumentation and software is a further limitation (Schmulian, 2002). Finally, the subjective interpretation of ABR results (wave forms) and the considerable amount of experience needed by clinicians to perform a successful ABR test make the use of this diagnostic procedure a less than satisfactory option (Swanepoel, 2001).

1.3 PROBLEM STATEMENT

From the above discussion, it is clear that current audiological procedures (behavioural and electrophysiological) cannot provide all the specified thresholds for determining fitness and compensability (Workmen's Compensation Commissioner, 1995). It is necessary to search for some

solution that can address all the needs related to diagnostic audiology in the mining industry in South Africa.

Is there an audiological technique available that can identify pseudohypacusis and, more importantly, estimate the true behavioural thresholds of pseudohypacusic mine workers with noise-induced hearing loss?

1.4 PROPOSED SOLUTION

From the discussion above, it is clear that the required audiological procedure for obtaining hearing thresholds for members of this unco-operative population needs to

- estimate behavioural thresholds accurately;
- estimate hearing thresholds at all the required frequencies, namely at 500, 1 000, 2 000, 3 000 and 4 000 Hz;
- estimate hearing thresholds accurately in workers with abnormal hearing, in all degrees of abnormal hearing ranging from mild to profound hearing loss;
- be independent of the patient's co-operation;
- be independent of the clinician's experience and perception; and
- be cost-effective.

The above criteria for an audiological solution to pseudohypacusis in the mining industry suggests that a possible solution may lie in the domain of auditory evoked potential testing.

A novel auditory evoked potential technique known as auditory steady state responses (ASSRs) was discovered and developed in Australia at the University of Melbourne during the 1980s (ERA Systems, 2000). This technique addresses the main shortcomings of ABR testing, in that it does not suffer from the spectral distortion problems associated with short-duration stimuli (Rance *et al.,* 1995). ASSRs are periodic scalp potentials arising in

response to regularly varying stimuli, such as amplitude and/or frequency modulated tones (Rance *et al.,* 1998).

Several authors have found a close correspondence between ASSRs and pure-tone thresholds (Reneau & Hnatiow, 1975; Rance *et al.,* 1998; Swanepoel, 2001; Schmulian, 2002). Rance *et al.* (1995) have developed a linear regression analysis to translate electrophysiological thresholds into a conventional audiogram to within 10 dB in 96 per cent of cases.

ASSR is a frequency-specific technique used for the estimation of hearing status. This technique was considered as a possible solution to the problem of pseudohypacusis, because all frequencies required for compensation purposes can be tested (John, Dimitrijevic & Picton, 2002) via the measurement of auditory evoked potentials (Picton, 2001). Electrical activity is evoked by frequency-specific tonal stimuli within the standard range of 250 to 8 000 Hz (ERA Systems, 2000). When the stimulus is presented at or above the hearing threshold, hair cells in the cochlea are activated in the region that is sensitive to the primary frequency of the tone. ASSRs can thus be elicited at all the frequencies needed for compensation and fitness for duty assessments. Lins *et al. (*1996) have further proven that the configuration of the hearing loss does not have an influence on the accuracy of ASSR results.

The validity of ASSR thresholds has been more extensively researched in populations with normal hearing (Schmulian, 2002) than on other populations. Limited research on other populations also seems to indicate that ASSR testing is a suitable substitute for pure-tone testing in people with hearing loss (Schmulian, 2002). Rance *et al.* (1995) mention the further positive point in the prediction value of ASSRs, in that ASSRs give more accurate estimates of hearing thresholds in pathological ears, possibly due to the effect of recruitment.

Apart from the fact that no response is required from the patient, analysis of the results of this test requires no visual or subjective evaluation from the clinician, as computer-based algorithms are applied to the recorded signals

(Perez-Abalo *et al*., 2001). The latter feature has been an elusive criterion in auditory evoked potential testing thus far. If no interpretation is required by a clinician, true objectivity is possible. Lack of experience among clinicians is also not longer a problematic factor.

From the above discussion of the features of ASSR testing (which are more extensively discussed in Chapter 4), it seems possible that this technique could provide a solution to the problems of an audiological evaluation of pseudohypacusic mine workers.

The implementation of ASSR testing in audiological assessments of noise-induced hearing loss cases, and particularly pseudohypacusic cases, offers the potential benefits of accurate threshold determinations, with significant cost savings for employers and their insurers, due to the elimination of overcompensation and unnecessary referrals and retests. Savings through the elimination of unproductive shifts are also envisaged. Secondary benefits include greater efficiency at audiological test centres. The application of current knowledge and state-of-the-art methods ensure that internationally accepted best practice is followed in the evaluation of noise-induced hearing loss.

With the above possible contribution (knowledge) of ASSR in mind, the following research question can thus be explored: ***What is the clinical value of auditory steady state responses in the audiological evaluation of pseudohypacusic mine workers with noise-induced hearing loss?***

Schmulian (2002) has found in a review of the relevant literature that ASSR has, so far, had limited clinical and research validation. Previous studies have focused mainly on small experimental groups with normal hearing. This study could thus enhance current knowledge by using a significantly large experimental group and by focusing on noise-induced hearing loss (no previous research in this area could be found).

1.5 PURPOSE OF THE STUDY

The purpose of this study is to evaluate the value of ASSR testing as an efficient and objective method to estimate hearing thresholds for compensation purposes, with specific reference to mine workers who display pseudohypacusis and noise-induced hearing loss.

1.6 CLARIFICATION OF TERMINOLOGY

The terms below are used in this study and must be clarified.

1.6.1 AUDITORY EVOKED POTENTIAL (AEP)

AEPs are very small electrical voltage potentials originating from the nervous system and recorded from the scalp in response to auditory stimuli (Picton, 1991).

1.6.2 AUDITORY STEADY STATE RESPONSE (ASSR)

An auditory steady state response (ASSR) is an auditory evoked potential arising in response to regularly varying stimuli, such as sinusoidal amplitude- and/or frequency-modulated tones (Rance *et al*., 1998). Although the acronym SSEP (steady state evoked potential) is probably a more correct term, Sininger and Cone-Wesson (1994) conclude that ASSR has become the term of choice.

1.6.3 NOISE-INDUCED HEARING LOSS (NIHL)

Noise-induced hearing loss is a sensory neural hearing loss caused by noise exposure. A decrease in hearing is typically seen first in the frequency range from 3 000 to 6 000 Hz. Hearing loss is usually symmetrical (Roeser, *et al.,* 2000b)

1.6.4 PSEUDOHYPACUSIS

"Pseudohypacusis" is the generally accepted term used to indicate a hearing loss greater than can be explained by a disorder in the auditory system. *"Pseudo*" indicates falseness and "*hypacusis"* a less than normal auditory sensitivity, or hearing loss (Martin, 1994, 2000; Roeser *et al.,* 2000b).

1.7 OUTLINE OF THE STUDY

To address the research question set out in Section 1.4 above, this thesis is organised as set out below.

- **CHAPTER 1: INTRODUCTION**

The problem of the high incidence of noise-induced hearing loss is explained. Noise-induced hearing loss costs the mining industry millions of Rands in compensation and its effects are further compounded by the high incidence of pseudohypacusis. Some workers exaggerate hearing loss and are unco-operative during audiological evaluations. This lack of co-operation in the hope of gaining monetary reward leads to problems in obtaining accurate assessments of workers' hearing thresholds, as required to estimate compensation and make recommendations on fitness for duty. In consequence, numerous retests are done and specialist referrals are made in the process of searching for true hearing thresholds. This further escalates costs, and leads to frustration and ineffectiveness at audiological test centres.

A new AEP, ASSR testing, is put forward as a possible solution to the problem of identifying pseudohypacusic mine workers. This technique has the potential to address the shortcomings of ABR testing (the test of choice where patient co-operation is absent up to this point in time).

- **CHAPTER 2: PSEUDOHYPACUSIS AND APPROPRIATE STRATEGIES TO DETECT AND QUANTIFY THE CONDITION**

The phenomenon of pseudohypacusis is discussed to enable the research question to be addressed. Pseudohypacusis is defined, and the reader is

familiarised with the acronyms used in the relevant literature. The prevalence of and etiological factors involved in pseudohypacusis are discussed concurrently, since prevalence is closely linked to motivating factors.

The role of current audiological procedures in detecting pseudohypacusis in the unco-operative population of mine workers who hope to gain compensation is evaluated. Most of the current techniques and tests that have become obsolete fail to establish true hearing thresholds. Hence the audiological profession has turned to electrophysiological measures, since no response is needed from the patient when using these tests. In the discussion of pseudohypacusis, the limited knowledge about its prevalence and the shortcomings of the audiological strategies used in the South African mining industry are evaluated.

- **CHAPTER 3: ELECTROPHYSIOLOGICAL TESTS AND THEIR USE IN THE ASSESSMENT OF PSEUDOHYPACUSIS**

Electrophysiological tests are dealt with in Chapter 3. The discussion of these tests is the logical next step since, historically, audiologists have turned to these tests as a solution to the problem of identifying pseudohypacusic patients. These tests require no behavioural response from patients, and are thus seen as objective tests. It is thus clear why audiologists have relied on these types of tests in dealing with difficult-to-test populations.

Different types of electrophysiological tests are described and evaluated. Electrical responses to auditory stimuli originating in the central nervous system and in reflexive muscular responses are sub-groups of electrophysiological tests.

Auditory evoked potentials (AEPs) are discussed in more detail, and attention is paid to nomenclature and definitions of AEPs. The history and development of AEPs also receive attention, as does the problematic classification of auditory evoked potentials.

The measurement of AEPs is deliberated with specific reference to the system requirements for amplification, signal averaging and the stimuli used.

Finally, different auditory evoked potentials currently known are described with reference to the latency epoch after stimulation. ABR, the most popular auditory evoked potential method used in clinical audiology and in the South African mining industry, receives the most attention.

- **CHAPTER 4: AUDITORY STEADY STATE RESPONSES (ASSRs) AND PSEUDOHYPACUSIS**

ASSR, a new and objective test for hearing threshold estimation, is central to this literature evaluation. Arguments explaining the rationale for choosing this particular AEP to feature in the empirical part of the research are supplied.

Different acronyms used for this AEP are listed, and definitions are set out. After its historical development has been explained, the advantages and disadvantages of this novel audiological technique are discussed in order to evaluate it critically as a possible solution to the research question.

No discussion of ASSRs would be complete without an explanation of the types of stimuli that are used in eliciting the AEP. Stimulus intensity, carrier frequencies and modulation frequency are also important information in the stimulation of this evoked potential. Two different stimulation methods, namely monotic and dichotic stimulation, are explained.

This chapter sets out the apparatus used, the influence of the subject on the test and the objective analysis of the results. The chapter concludes with the response generators of ASSRs and the application of this procedure in clinical audiology. This application is very important, since it also influences the potential application in the difficult-to-test experimental group.

- **CHAPTER 5: RESEARCH METHODS**

The literature reviews of pseudohypacusis (Chapter 2), electrophysiological tests (Chapter 3) and ASSRs (Chapter 4) provide a scientific basis for the methodology of the experimental research.

An empirical study tested the clinical value of ASSR tests for a sample of mine workers with noise-induced hearing loss in selected gold mining companies in Randfontein and Carletonville in South Africa.

The principal and sub-aims of the experimental research are put forward, after which the research design is explained. The group of mine workers with noise-induced hearing loss tested using ASSR consisted of five subgroups, for which the effects of sedation, monotic and dichotic stimulation and different modulation frequencies were compared. The experiment on this first group (Phase 1) was planned to provide the best ASSR method, which was subsequently tested in a group of mine workers with pseudohypacusis (Phase 2), to establish whether ASSR methods can conclude the audiological test procedures for this group and lead to meaningful recommendations.

Data collection apparatus and procedures are highlighted with reference to pure-tone testing and multiple-frequency and single frequency ASSR testing. Finally, the data analysis apparatus and procedures are explained.

- **CHAPTER 6: RESULTS**

The value of any diagnostic test depends on its ability to fulfil its intended purpose (Roeser *et al*., 2000b). Data obtained in this study was analysed, organised and presented to demonstrate that ASSR thresholds can fulfil its intended purpose in the normative group of mine workers with noise-induced hearing loss, as well as in the pseudohypacusic group.

This study proves that ASSR testing is sensitive enough to estimate behavioural thresholds in a population of mine workers with abnormal and noise-induced hearing loss, and that, if workers exaggerate their hearing loss,

ASSRs can estimate the true thresholds and thus conclude the diagnostic procedures with the correct recommendations regarding the fitness, compensability and further handling of the patient.

- **CHAPTER 7: CONCLUSIONS AND RECOMMENDATIONS**

Having shown the value of ASSR testing in the experimental research, the thesis concludes by critically evaluating the research and its limitations, making recommendations for further research and the implementation of this procedure in practice.

1.8 SUMMARY

This chapter has described the problems audiologists face in identifying and quantifying pseudohypacusic noise-induced hearing loss patients in the South African mining industry. Conventional tests do not provide the accurate hearing thresholds required for compensation purposes, especially when patients are unco-operative or attempting to deceive. Unless it can measure accurate thresholds, the mining industry stands to suffer monetary loss, audiologists' effectiveness is impaired and cases are rarely concluded. A study of ASSR testing is proposed as a solution for the shortcomings of existing audiological procedures. The research problem has been formulated, and an outline of the thesis is provided. The second chapter is intended to explore pseudohypacusis as the reason why this study was necessary. It shows why audiology is sometimes an art, rather than a science when one is working with a pseudohypacusic population (De Koker, 2003).

CHAPTER 2

PSEUDOHYPACUSIS AND APPROPRIATE STRATEGIES TO DETECT AND QUANTIFY THE CONDITION

AIM

To define and describe the phenomenon of pseudohypacusis and to analyse and evaluate the audiological strategies currently available to audiologists to detect this phenomenon.

2.1 INTRODUCTION

In Chapter 1, the high incidence of exaggerated hearing test results in the South African mining industry, as well as the negative impact this exaggeration potentially has in terms of cost and the effectiveness of audiological centres, was described. This sets the scene for this study which attempts to evaluate one possible way to address deliberate exaggeration of hearing loss on the part of noise-exposed mine workers.

Deliberate and potentially deceptive exaggeration of hearing loss is called “pseudohypacusis” (Martin, 1994). The phenomenon of pseudohypacusis is examined in this chapter in terms of its prevalence and causative factors in order to make it possible to evaluate better possible alternatives to present audiological methods used in the assessment of workers who present with this problem. This discussion not only looks at audiological methods able to detect pseudohypacusis, but specifically addresses the techniques employed in determining hearing thresholds. In searching for an audiological solution to pseudohypacusis, the first step is to define the phenomenon of pseudohypacusis.

2.2 DEFINITION OF PSEUDOHYPACUSIS

Hearing loss greater than that which can be explained solely by a disorder within the auditory system has been variously described as non-organic hearing loss, pseudohypacusis/pseudohypocusis, psychogenic hearing loss, feigned hearing loss, malingering, functional hearing loss, conversion deafness and simulated hearing loss (Rintelmann *et al.,* 1991; Martin, 1994, 2000; Roeser *et al.,* 2000b). Rintelmann *et al.* (1991:381) define pseudohypacusis, from the point of view that "the patient exhibits a hearing loss in some fashion but where there is no organic basis readily apparent for the disorder". To summarise: pseudohypacusis refers to false or exaggerated hearing thresholds "measured" due to a lack of co-operation from the patient.

Recent literature suggests that pseudohypacusis is the most widely used term for this phenomenon at the moment. It is also clear that there is very limited new research on this phenomenon. Audiological textbooks (Roeser *et al.,* 2000b; Martin, 2000) summarising research in this field refer mainly to research done in the 1960s and 1970s. More recent literature on pseudohypacusis and especially in the field of noise-induced hearing loss is limited, but authors such as Rickards and De Vidi (1995), Qiu *et al.* (1998) and Rickards *et al*. (1996) deserve to be mentioned as making some contributions.

The phenomenon of pseudohypacusis can be better understood within the framework of the prevalence and etiology of this condition, which are interrelated.

2.3 PREVALENCE AND ETIOLOGICAL FACTORS

The basis of pseudohypacusis, according to Qiu *et al*. (1998), can be conscious (malingering) or unconscious (psychogenic). From a clinical position, it is clear that it is difficult to determine whether a false threshold is the result of a conscious or an unconscious motive and it is thus more appropriate to refer to this phenomenon only in terms of the concept of

false/less than true *(pseudo*) hearing loss *(hypacusis*). It is also important to remember that feigned hearing thresholds can be superimposed on a true organic component (Roeser *et al.,* 2000b). In this regard, researchers have proven that pseudohypacusis is more frequently superimposed on a true organic component than on normal hearing sensitivity (Qiu *et al.,* 1998*).*

A number of factors may encourage a person to feign a hearing loss that does not exist or to exaggerate one that does. The reasons for pseudohypacusis can be classified as two groups, based on the financial and/or the psychological gain a patient wishes to obtain (Roeser *et al*., 2000b). From this, it can be concluded that the prevalence of pseudohypacusis is highly variable, depending on the population examined (Rintelmann *et al.,* 1991). Since the prevalence of pseudohypacusis is so closely linked to potential causative or motivating factors, these two aspects are dealt with concurrently in the discussion below.

Rickards *et al*. (1996) have shown that pseudohypacusis plays a significant role in noise-induced hearing loss claims and in their financial impact on employers. They have reviewed studies that have found that the prevalence of pseudohypacusis varies between nine and 30 per cent of compensation claims, and they add that 18 per cent of noise-induced hearing loss claimants in the Australian state of Victoria are referred for evoked response testing, indicating that true thresholds cannot be established through conventional methods.

Qiu *et al. (*1998) estimate the prevalence of pseudohypacusis in the military to be between 15 and 20 per cent of referrals from the US Veterans' Administration. It is also interesting that, in a review of the literature, it has been found that the prevalence of pseudohypacusis is greatest among adult workers who may qualify for monetary compensation if occupational hearing loss can be demonstrated (Rintelmann *et al*., 1991). It also seems that the phenomenon is increasing. In one study, it was found that service-connected, non-organic hearing loss had increased from ten per cent to nearly 60 per

cent in the ten years following World War II (Johnson, Work & McCoy, 1956). Martin (1994) cites a study that found that 24 per cent of 116 workers applying for compensation were pseudohypacusic. Martin (1994) points to an increase in the number of pseudohypacusic cases since the implementation of laws regulating noise in the workplace in the USA.

The incidence of pseudohypacusis in South Africa has not yet been studied, but audiologists consulting in the mining industry regard it as significant. De Koker (2003) has kept records of 160 cases referred for compensation evaluations during a three-month period in 2002. Of these, 32 per cent were found to have exaggerated their hearing loss An increased prevalence of pseudohypacusis has been noted in South Africa since the implementation of the Workmen's Compensation Commissioner's (1995) Instruction 168. Industry-wide, this could partially account for the dramatic increase in noise-induced hearing loss claims since 1995 (De Koker, 2003). This instruction lowered the "fence" for compensation from a 42 dB average hearing loss to 26 dB. This entitled more workers to compensation, resulting in an escalation of mining industry claims for noise-induced hearing loss from eight per cent of all claims for disease and injury to the current level of 14 per cent (Begley, 2001). It is possible that workers' awareness of the potential for monetary gain from hearing loss has also increased, and that this is apparent from the behaviour of patients during noise-induced hearing loss evaluations.

The foregoing discussion can perhaps lead to a wrong conclusion that all pseudohypacusic cases are associated with monetary gain. Psychological factors also contribute to the prevalence of pseudohypacusis (Martin, 1994; 2000). Some of the most important studies of social and psychological factors associated with this phenomenon are summarised in Table 2.1 (overleaf).

TABLE 2.1: PSYCHOLOGICAL ANOMALIES FOUND IN PSEUDOHYPACUSIC PATIENTS

TYPES OF ANOMALIES	PSYCHOLOGICAL/SOCIAL ANOMALIES	SOURCE
Behavioural anomalies	• Avoidance of undesirable situations	Martin, 2000
	• Emotional disturbances	Trier & Levy, 1965
	• Tendency to hypochondria	Trier & Levy, 1965
	• Diminished confidence in meeting needs of everyday life	Martin, 1994
	• Deviant social behaviour	Gold, Hunsaker & Haseman, 1991
	• High incidence of personality disorders	Gold *et al*., 1991
	• Lack of adjustment to hearing loss	Martin, 1994
Financial status	• Lower socio-economic status	Trier & Levy, 1965
Symptoms impacting on health	• Psychosomatic complaints	Gold *et al*., 1991
Intelligence anomalies	• Lower levels of verbal intelligence	Trier & Levy, 1965
	• Poor academic achievement	Gold *et al*., 1991

One can deduce from the above table that it is possible for pseudohypacusic patients to have deviant emotional/social adaptation and symptoms, but also that they may fall into a lower socio-economic class, which might explain their malingering for financial gain. Lower levels of verbal intelligence could also add to the belief that they will be able to exaggerating a hearing loss.

The question of why a pseudohypacusic patient claims to have a hearing loss and not some other type of disability can be raised. Martin (1994) suggests that a patient may select this disorder in consequence of a previous incident or circumstance that has focused his attention on hearing, for example, an ear infection, physical trauma to the ears, tinnitus or noise exposure. This suggestion is particularly relevant for the mining industry. It is certainly true that a high incidence of noise-induced hearing loss is already present in this population, and this increases the awareness of hearing loss. Most mine workers are also male, and thus carry the burden of being breadwinners. Receiving a settlement amount of thousands of rands for a hearing loss is often their only way of ever accumulating a sizable amount of money (Geyser, J., 10 March 2003: personal communication).

From the above it is clear that there is some disagreement in the literature about whether pseudohypacusis is psychogenic, or deliberately and consciously chosen in the hope of personal gain. Goldstein (1966) suggests that psychogenic (unintentional), cases of exaggerated hearing loss do not exist, and that all pseudohypacusis cases are conscious pretences. The experience of many audiologists in the mining industry suggests that this is often the case where compensation is involved (De Koker, 2003).

2.4 AUDIOLOGICAL ASSESSMENT OF PSEUDOHYPACUSIS

In dealing with pseudohypacusic patients, audiologists face a twofold challenge. The first is the detection of pseudohypacusis, and the second the determination of true hearing thresholds in such patients (Martin, 2000). The audiologists' responsibility goes further, taking into account the need for rehabilitation: "identification of pseudohypacusis is extremely important not only to ensure that the *patient receives appropriate intervention but also to avoid potentially harmful intervention.*" (Roeser *et al*., 2000b:329, own emphasis).

It is thus clear that appropriate, relevant and practical audiological procedures are imperative to ensure correct, relevant and professional management of

pseudohypacusic workers. Current audiological testing methods and existing clinical knowledge do contribute to the detection of pseudohypacusis, but very often fail to establish true hearing thresholds. Some of the audiological indicators used in the detection of pseudohypacusis are discussed below.

2.4.1 REASON FOR REFERRAL

In many cases, the reason for the referral of the patient in itself suggests the possibility of pseudohypacusis, for example, when a patient is referred in order for the audiologist to investigate or evaluate a compensation claim (Qiu *et al*., 1998). Martin (2000) points out that referrals from attorneys and the veterans' administration should alert audiologists to the possibility of pseudohypacusis. In practice, often this problem is suggested when a patient already has an extensive file of previous tests and specialist opinions.

2.4.2 PATIENT BEHAVIOUR

Patient behaviour during the interview and test situation very often aids audiologists in detecting pseudohypacusis.

Information gathered by a skilled clinician in informal observation of the patient before and during the taking of the case history is helpful in the diagnosis of pseudohypacusis (Roeser *et al.*, 2000b). The patient's body language can feign reliance on lip-reading, and he may also ask the interviewer to repeat questions or instructions. This is not common in people with true loss of hearing (Martin, 2000). In the author's experience, pseudohypacusic patients very often claim to suffer from symptoms associated with hearing loss, and tend to exaggerate these symptoms. So for instance, they answer in the affirmative to all symptoms that the clinician inquires about.

The above indicators of pseudohypacusis are not always available to all audiologists in the South African mining industry, since language and communication barriers can arise, especially because foreign workers are

employed. In such cases, the interpreters employed in audiological centres need to be made aware of a possible exaggeration of symptoms, and to receive training in interviewing skills. These interpreters also need a basic knowledge of how hearing loss and particularly different degrees of hearing loss affect communication behaviour.

Discrepancies between audiometric results and a patient's social functioning should also alert clinicians to the possibility of pseudohypacusis. It is impossible for a patient with profound bilateral hearing loss to respond appropriately to questions or instructions presented at a normal conversational level of 50-60 dB, particularly if any attempt to lip-read is subverted (Martin, 1994).

Extremely slow and deliberate responses, according to Martin (1994), are indicative of pseudohypacusis, because most people respond immediately to test signals. The experience of the researcher supports the contention that audiologists should suspect pseudohypacusis where patients responded slowly. Finally, Gold *et al.* (1991) state that exaggerated body movements and facial expressions (for example, sitting on the edge of the chair and grimacing as if to suggest extreme concentration) should be regarded as possible signs of pseudohypacusis.

2.4.3 PURE-TONE AUDIOMETRY

Martin (1994) identifies two types of potential error in the determination of pure-tone thresholds, namely false-negative and false-positive responses. Failure to respond at levels above the true threshold constitutes a false-negative response, which is the most important characteristic of pseudohypacusis.

According to Qiu *et al.* (1998), it is not difficult for an audiologist to detect pseudohypacusis using conventional audiological procedures. This may be true for experienced audiologists but, unfortunately, inexperienced audiolo-

gists often fail to scrutinise patients' behaviour and other indicators of underlying intentions, and hence may not detect the presence of exaggerated hearing loss. Using current methods, considerable time and effort may be needed for the evaluation of pseudohypacusic cases if lack of co-operation is not detected by a clinician. Nevertheless, pure-tone audiometry, as part of the basic audiological assessment battery, plays a very important role in the detection of pseudohypacusis. Pure-tone audiometry is also prescribed in the current South African legislation. Instructions 168 and 171 of the Workmen's Compensation Commissioner specify that a response to 500, 1 000, 2 000, 3 000, 6 000 and 8 000 Hz needs to be tested for compensation purposes (Workmen's Compensation Commissioner, 1995).

Pure-tone audiometry can assist in the detection of pseudohypacusis in the following ways set out below.

2.4.3.1 Inconsistent thresholds

Rintelmann *et al.* (1991) state that the best indicator of pseudohypacusis is inconsistent tests responses. Where two threshold determinations for the same frequency differ by more than 15 dB, the results can be treated as inconclusive. Repeating the test with an intervening time lapse is intended to confound any attempt to consistently exaggerate a hearing loss. The current practice of performing two pure-tone air-conduction tests on the same day but at different sittings for potential compensation cases allows for an identification of possible pseudohypacusis before any further testing is done (Workmen's Compensation Commissioner, 1995). However, it is important to remember that this is not an infallible detection method, since Haughton *et al.* (1979) have found that subjects with normal hearing asked to feign hearing loss during three tests over a two-week period were able to duplicate their feigned loss to within 6 dB, on average. This raises the concern that self-discipline and familiarity with the test procedure could enable workers to feign hearing loss consistently and qualify falsely for compensation or for inflated settlements.

2.4.3.2 Different pure-tone threshold determination methods

Rintelmann *et al.* (1991) recommend a procedure that may well be the most effective and time-efficient method for detecting pseudohypacusis when using pure tone audiometry. They recommend the use of two pure-tone air-conduction tests using different presentation methods. Patients who attempt to simulate hearing loss often try to select a level above their true threshold as a reference for recording consistent above-threshold responses. To counter this tactic, it is recommended that the first test be presented using the ascending method, and that the second test use the descending method (Martin, 1994; Roeser *et al.,* 2000b). When it is applied to pseudohypacusic patients, this procedure generally results in significant discrepancies between the two pure-tone tests, thereby identifying the patient as pseudohypacusic.

2.4.3.3 Audiometric configuration

Another indication of pseudohypacusis using pure-tone audiometry as a method of detection is the shape of the audiometric curve. A flat configuration is very often an indication of pseudohypacusis (Martin, 1994). So, for instance, it may be found that all the thresholds in one or both ears are at the same intensity, therefore presenting a straight line on the audiogram. (This is uncommon in audiology).

2.4.3.4 Lack of interaural attenuation

Roeser *et al.* (2000b) are of the opinion that many pseudohypacusic patients feign unilateral hearing loss.

In the case of a true unilateral hearing loss, a patient reacts to loud sound presented to the poorer ear, due to the fact that the intensity of the sound presented to the poorer ear is sufficient to cross to the other (better) ear. This crossover involves the transmission of sound emanating at the test ear to the cochlea of the non-test ear (Stach, 1998). In the case of a true unilateral hearing loss, the patient stops reacting to the sound with the better ear as soon as the better ear is masked and is thus removed from the test situation.

A naïve pseudohypacusic patient indicates no hearing in one ear and good hearing in the other, which is impossible given the preceding discussion of interaural attenuation (Martin, 1994).

The phenomenon of interaural attenuation is of particular importance with bone-conduction testing, since the lower limit of interaural attenuation is essentially 0 dB across frequencies. Thus, regardless of bone conductor placement, both cochleas will be stimulated equally and simultaneously, and the better cochlea should thus prompt a response (Stach, 1998). A pseudohypacusic patient does not normally respond with the bone conductor placement on the chosen weaker ear.

2.4.3.5 Lack of correlation between air- and bone-conduction tests

A further indication of pseudohypacusis in pure-tone testing is commonly a lack of correlation between bone- and air-conduction results.

It is impossible for bone-conduction results correctly to indicate worse hearing than air-conduction results, since air-conduction results have already given an indication of the status of the whole hearing mechanism. It is therefore impossible for a sub-section of that tested mechanism to be worse than the whole. A second indication of pseudohypacusis is a false air-bone gap (Qiu *et al.,* 1998). When an audiologist is presented with an air-bone gap it usually means that an outer or middle ear problem is impeding the conduction of sound to the cochlea (Dirks, 1973). Pseudohypacusic patients sometimes present with a conductive hearing loss that cannot be verified by an otoscopic examination, medical history or, most importantly, the results of immittance testing (Qiu *et al.,* 1998; De Koker, 2003).

2.4.4 SPEECH TESTING

In the diagnostic audiological battery available to audiologists, pure-tone tests are commonly perceived as the gold standard for evaluating the specific effects of auditory system pathological conditions. However, pure-tone

measurements provide only limited information about the communication difficulties a patient may experience, or the site of the lesion (Roeser *et al.,* 2000b). It is therefore imperative to apply a test battery to cross-check the pure-tone information. In the case of pseudohypacusic patients, clinicians usually rely on the ability of speech audiometry to assess the validity of the pure-tone thresholds.

2.4.4.1 Speech reception thresholds

Discrepancies between the speech reception thresholds (SRT) and the pure-tone average (PTA) can indicate pseudohypacusis. Gold *et al.* (1991) regard a difference of 15 dB between the PTA and SRT (with the PTA as the higher threshold) as an indication of pseudohypacusis. Roeser *et al.* (2000b) regard even an 8 dB difference as significant. In the case of people who respond truthfully, however, the two parameters generally correspond closely. It is therefore realistic to assume that any discrepancy, in the absence of a reasonable explanation for it (for example, the slope of the audiogram or poor word discrimination), is thus indicative of pseudohypacusis (Martin, 1994).

Apart from the above discrepancy between SRT and PTAs, it has also been noted that pseudohypacusic patients often respond to spondee words by repeating only half of the word, for example “dog” for “hotdog” (Gold *et al.,* 1991). Since SRT constitutes a threshold determination test, it could be the first step in a patient’s evaluation, followed by pure-tone testing. This corresponds with the recommendation of Rintelmann *et al*. (1991) to avoid supra-threshold tests at the beginning of audiological procedures. Furthermore, most South African mine workers are very familiar with pure-tone air-conduction procedures as a result of annual screening, but few have had exposure to speech audiometry, and thus discrepancies between PTA and SRT results can be indicators of pseudohypacusis.

2.4.4.2 Word discrimination tests

When considering word discrimination test results, Gold, Hunsaker and Haseman (1991) report pseudohypacusic patients with hundred per cent discrimination scores at levels equalling, or slightly exceeding, admitted pure-tone thresholds. This phenomenon should alert a clinician to the possibility of pseudohypacusis, since hundred per cent discrimination is usually achieved only at a sensation level of 30 to 40 dB (Stach, 1998).

As is the case with pure-tone testing, some indicators of pseudohypacusis can also be found in the behaviour of the patient during the test. Roeser *et al.* (2000b) report a lack of patient co-operation during word discrimination testing, stating that patients tend to get all words right once, and then start missing all words.

2.4.5 SPECIAL TESTS

A review of the literature indicates that several specialised audiometric tests have been developed to identify pseudohypacusis, including:

- the Stenger test (Chaiklin & Ventry, 1965);
- automatic audiometry (Jerger, 1960);
- delayed auditory feedback (Martin, 1994);
- the swinging story test (Martin, 1994);
- pulse-count methods (Ross, 1964) ;
- the yes-no test (Frank, 1976) ;
- the Doerfler-Stewart test (Doerfler & Stewart, 1946);
- the Lombard test (Simonton, 1965);
- the forced choice procedure (Haughton *et al.*, 1979); and
- electrodermal audiometry (Gold *et al.,* 1991).

Roeser *et al. (*2000b) label these tests “historical tests” that are not routinely used in daily audiological practice. The reasons they are not used can be sought in their involving long and complicated procedures, requiring special equipment, and most importantly, them being unable to determine true hearing

thresholds. In a clinical situation, particularly in the mining industry, where large numbers of workers impose large caseloads on audiologists (Franz, 2003), there is little to be gained from tests that confirm the presence of pseudohypacusis without establishing true hearing thresholds. The only one of these tests that is quantitative in nature is the Stenger test, but this is primarily useful in the detection of feigned unilateral hearing loss, which is not common in the mining industry.

Accurate and objective information on hearing thresholds is crucial to the evaluation of compensation claims and to determining workers' fitness (RMA guidelines, 2003). This need, along with the high incidence of pseudohypacusis among noise-exposed workers, has led many audiologists to employ electrophysiological procedures to estimate true hearing thresholds. Roeser *et al.* (2000b) have also focused attention on the fact that electrophysiological tests are quantitative, unlike the qualitative conventional and historical tests described in this chapter.

Roeser *et al*. (2000b) argue that, in cases where true thresholds cannot be obtained, electrophysiological evaluations are indicated. It is thus necessary for audiologists to move beyond the identification of pseudohypacusis to the estimation of true thresholds. All audiological procedures discussed up to this point have aided only in the detection of pseudohypacusis.

2.5 SUMMARY

Pseudohypacusis, where a patient feigns or exaggerates hearing loss, has been examined in terms of the very limited information in the existing literature. Definitions have been offered, and the prevalence and causative/-motivating factors have been discussed. Means of identification of pseudohypacusis by audiologists have also been highlighted.

Most of the available test procedures failed to assist clinicians in objectively determining true hearing thresholds, especially within reasonable limits with regard to time and cost. The researcher is of the opinion that there is little to

be gained from performing an array of specialised and time-consuming tests that fail to provide accurate hearing thresholds.

The test of choice for identifying pseudohypacusis remains the pure-tone audiogram. Hence, the answer in the search for an objective test with which to estimate pure-tone behavioural thresholds appears to lie in the realm of electrophysiological tests, which will be the subject of the next chapter.

CHAPTER 3

ELECTROPHYSIOLOGICAL TESTS AND THEIR USE IN THE ASSESSMENT OF PSEUDOHYPACUSIS

AIM OF THE CHAPTER

To evaluate the usefulness of the electrophysiological tests available, specifically auditory evoked potentials, in the audiological evaluation of pseudohypacusic patients. The main question addressed is: what contribution electrophysiological tests can make to the detection of pseudohypacusis and the determination of thresholds in the difficult-to-test population of mine workers.

3.1 INTRODUCTION

"All diagnostic procedures are designed to identify the presence of the disorder as early as possible. That is, the procedure must accurately identify those patients with the disorder while clearing those patients without the disorder" (Roeser *et al*., 2000b:12). This requirement for audiological test procedures is met by the tests described in Chapter 2, in that the conventional tests can **identify** pseudohypacusis.

The audiologist's responsibility goes further: it is not only to identify the presence of a disorder, but to quantify it, thus to determine frequency-specific hearing thresholds for all patients assessed, in order to provide guidance for the rehabilitation process, as well as to facilitate recommendations and decisions regarding patient referrals (Stach, 1998; Roeser *et al.,* 2000b). Schmulian (2002) supports this position, commenting that poor and inaccurate diagnostic procedures result in sub-standard recommendations regarding the rehabilitation of the disorder.

In the field of medico-legal investigations, there is a further reason for not only identifying but also quantifying the hearing loss, namely financial loss. Coles

and Mason (1984:71) clarify the importance of true hearing threshold estimation as follows: "In medico-legal investigations of all kinds, precautions have to be taken against falsification of disability by the patient since there is a clear motivation for him to exaggerate and thereby obtain greater financial advantage. This is particularly necessary where the disability claimed can only be fully characterized by including subjective aspects, as in the case of hearing loss."

This is certainly of particular relevance for mine workers with noise-induced hearing loss who present with pseudohypacusis. A pseudohypacusic worker's lack of co-operation confounds efforts to obtain accurate frequency-specific information, and often leads to large numbers of pending cases. These workers have to be retested, which increases the cost of audiological and other specialist assessments. Retesting workers also leads to additional expenditure (further financial implications), since these workers miss shifts and the mining company thus loses production. Additional transport costs may also be involved if workers are referred for further assessments.

The lack of the availability of accurate hearing thresholds results in situations where compensation is not paid to deserving cases and in overcompensation of genuine noise-induced hearing loss where hearing threshold inconsistencies are not detected. The frustration of audiologists, occupational health centre staff and the mining industry in general is understandable.

Abramovich (1990), Martin (1994) and Schmulian (2002) state that a lack of patient co-operation, irrespective of the cause or motivation, necessitates the use of additional, more objective (and sometimes more costly) procedures, and that other responses apart from behavioural responses to acoustic signals should be explored for the estimation of hearing thresholds.

In the assessment of hearing, audiologists have always used a test battery approach (Hall & Mueller, 1997) to ensure acceptable service delivery to clients. The various tests available to audiologists are used in conjunction

with each other and allow for cross checks to confirm results. With a pseudohypacusic patient, such efforts generally confirm the presence of pseudohypacusis without quantifying its extent, in other words, tests fail to provide frequency-specific hearing thresholds.

The most reliable means of cross checking is provided by test procedures that require no voluntary response from the patient (Schmulian, 2002). Gorga (1999) indicates that assessments of pseudohypacusic patients require the use of test procedures that do not rely on voluntary behavioural responses. The quest for measures not requiring a behavioural response has led to the development of electrophysiological tests, which provide an objective assessment of auditory sensitivity (Hall, 1992). Rintelmann *et al*., (1991); Stach, (1998) and Roeser *et al. (*2000b) also promote the use of physiological tests for difficult-to-test populations.

Today, audiologists have a wide range of electrophysiological assessment tools to select from (Roeser *et al*., 2000b). These are examined and evaluated in this chapter. Particular attention is focused on auditory evoked potential (AEP) methods, which have been shown to provide estimates of hearing thresholds. The objective is to identify and evaluate audiological solutions and test procedures for the population of mine workers, in which noise-induced hearing loss is frequent and pseudohypacusis is rife.

3.2 ELECTROPHYSIOLOGICAL (EP) TESTS

3.2.1 QUALITATIVE EP TESTS (USED PRIMARILY FOR DETECTION OF PSEUDOHYPACUSIS)

Discoveries in the field of audiology (and other related fields, including neurology and electronics) have recently led to rapid advances in the development of electrophysiological tests (Ferraro & Durrant, 1994; De Waal, 2000; Roeser *et al.,* 2000b). Audiological assessment techniques no longer need to be limited to traditional behaviour-based psycho-acoustic tests, now

that EP tests can help satisfy the need to assess auditory sensitivity at specific frequencies objectively (Schmulian, 2002).

The EP methods used in the past thirty years have included immittance testing, acoustic reflex (AR) measurements, oto-acoustic emission (OAE) tests and auditory evoked potential (AEP) tests. Of the many electrical responses to auditory stimuli, most originate in the central nervous system. Some are generated in the cochlea, while others are reflexive muscular responses (Glasscock, Jackson & Josey, 1987).

Immittance and OAE measurements are not measures of hearing *per se*, but are means of evaluating the status of the auditory system at specific peripheral levels, although never as an entire system (De Waal, 2000). These measures do not provide frequency-specific thresholds, but merely confirm the suspicion of pseudohypacusis, thus serving as a means of cross checking.

3.2.1.1 Immittance

Acoustic immittance measures (tympanometry, static compliance and acoustic reflex) have been well established as a routine part of audiological evaluation (Rintelmann *et al.*, 1991). The primary application of acoustic immittance is the evaluation of organic hearing disorders. It can also be useful in the detection of pseudohypacusis.

Martin (1994) claims that the sophistication of automated middle ear tests may discourage pseudohypacusis, and is therefore very valuable in the detection or prevention of pseudohypacusis. Clinicians should thus remember to suggest to the patient that the test is fully automatic and that no response is needed, thereby removing the temptation to feign a hearing loss. It is therefore generally good practice to perform an immittance test first if this test can be used to avoid pseudohypacusis. This is a valid approach, but goes against the recommendation of Rintelmann *et al.* (1991) that supra-threshold tests should be performed after air- and bone-conduction tests. Experience

has shown that completing threshold testing before embarking on supra-threshold tests does save time and prevents unco-operative patients from finding a supra-threshold reference level (Dobie, 2001; De Koker, 2003).

The AR threshold is the most useful measurement in the detection of pseudohypacusis. In persons who have normal hearing, an acoustic reflex is usually elicited by means of contralateral stimulation at sensation levels that range from 70 to 95 dB. For persons with cochlear lesions, as in mine workers exposed to noise, the reflex may be obtained between 15 and 60 dB (Rintelmann *et al*., 1991). When the difference between the AR threshold and the voluntary threshold is extremely low (5 dB or less), the pure-tone threshold must be questioned on the basis of organic pathology (Martin, 1994; 2000). Claims of a profound unilateral or bilateral hearing loss can be refuted if the AR is present at normal stimulus levels, but the phenomenon of recruitment may limit the usefulness of AR measurements in estimating hearing thresholds, especially in cases of noise-induced hearing loss.

Tympanometry provides an immediate evaluation of the middle ear status. Present ARs and normal middle ear function are not compatible with conductive hearing loss (Qiu *et al*., 1998). If conductive hearing loss is present with normal middle ear function pseudohypacusis can be expected. The reason being mine workers' unfamiliarity with bone conduction testing.

AR measurements may be useful in estimating actual hearing thresholds by performing the sensitivity prediction with the acoustic reflex test (SPAR). Middle ear reflex thresholds for pure tones are compared with those for wide-band noise, as well as for filtered low- and high-frequency wide-band noise (Martin, 1994; 2000). In the researcher's experience, the high incidence of absent ARs in this population makes the use of the SPAR test impossible. Dobie (2001) also claims that the SPAR test has no clinical utility in pseudohypacusic populations. Some reasons for this, although Dobie (2001) does not mention them, could be elevated and absent ARs.

In conclusion as was the case with the behavioural tests described in Chapter 2 immittance testing predicts and detects pseudohypacusis but is not quantitative in nature.

3.2.1.2 Oto-acoustic emissions (OAE)

Small changes in the biomechanical function of the cochlea can be monitored by measuring OAEs, which are generated within the cochlea by active non-linear processes involving the outer hair cells (Kvaerner *et al.,* 1996).

It is impossible for a patient with compensable hearing loss to have normal OAEs, and OAE testing is thus advocated as a quick and objective means of confirming hearing status in suspected cases of pseudohypacusis (Qiu *et al.,* 1998). A patient with normal OAEs should have normal hearing thresholds. Unfortunately, the usefulness of OAE testing is limited in cases of noise-exposed patients, as such individuals often exhibit abnormal or absent OAEs with normal hearing as a result of pre-symptomatic cochlear damage (Hall, 2000; De Koker *et al*., 2003). So far, it has also been difficult to correlate OAEs and behavioural thresholds (Hall, 2000). OAEs are another qualitative assessment tool which is useful in the detection of pseudohypacusis.

3.2.2 QUANTITATIVE ELECTROPHYSIOLOGICAL TESTS (ESTIMATION OF HEARING THRESHOLDS IN PSEUDOHYPACUSIS)

3.2.2.1 Introduction

Despite the considerable interest that has been generated by all the conventional tests described in Chapter 2 and the electrophysiological tests of immittance and oto-acoustic emissions, as the foregoing discussion has indicated, none have provided accurate hearing thresholds in the case of pseudohypacusic mine workers. The problem faced when compensation is involved is that the audiologist must obtain ten hearing thresholds (South African legislation) that are accurate enough to be duplicated in a second test. The focus is thus on quantitative data.

Accordingly, attention needs to be paid to auditory evoked potential methods as the most useful and effective electrophysiological measure of auditory system function (Rance *et al*., 1998) with due consideration to both the peripheral and central auditory systems. Hood (1998) emphasises that EP tests are not tests of hearing, but tests of synchronous neural function and the ability of the central nervous system (CNS) to respond to external stimuli in a synchronous manner. Nevertheless, numerous authors have shown how closely thresholds from AEP testing correspond with behavioural thresholds (Reneau & Hnatiow, 1975; Rance *et al*., 1998; Barrs *et al*., 1994). This fact, combined with the statement of Abramovich (1990) that the verification of hearing loss and the validation of the pure-tone audiogram is important in dealing with compensation claims, supports the necessity of evaluating AEP tests within the framework of this study.

Hyde *et al*. (1986) argue even more strongly that, if AEPs are accepted as the ultimate arbiter in medico-legal evaluations, the rationale for interposing confirmatory tests (detection) between a suspicion of and the quantification of pseudohypacusis is suspect.

3.2.2.2 Background: the development of the use of AEPs

AEP procedures are not really a “new” technique. Glasscock *et al*. (1987) trace the origins of auditory brainstem response (ABR) testing to animal experiments in the nineteenth century, citing Caton, who reported electrical activity in the brain of a rabbit in 1875. They also mentioned other researchers who investigated electrical activity in the brains of other animals between 1883 and 1891.

Not only the technique but also the apparatus used to evoke and record the electrical responses has developed over the years. Pravdich-Neminsky photographed an apparatus to record animal electro encephalograms (EEGs) using a string galvanometer (Glasscock *et al*., 1987). During the 1930s, oscilloscope images were bright enough and electrical amplifiers stable

enough to allow neurophysiologists to concentrate on experimental work rather than on equipment problems (Abramovich, 1990).

Berger first observed spontaneous electrical activity of the type now routinely recorded during EEGs in 1929 (Abramovich, 1990; Ferraro & Durrant, 1994). In searching for electrical activity in the inner ear, Wever and Bray (1930) recorded potentials in response to auditory stimuli from the round window of a cat. These potentials have since been termed cochlear microphonic or CM (Abramovich, 1990).

The main problem facing early researchers was the difficulty of measuring very small potentials in isolation from other electrical activity within the brain. Particular difficulty was experienced when the stimuli were of low intensity, as EEG voltage was much greater than the voltage of the evoked potential (Reneau & Hnatiow, 1975). The development of averaging computers has facilitated more accurate analysis of small bio-electrical signals (Abramovich, 1990). Glasscock *et al.* (1987) note that Davis acquired a digital computer in 1961, after which he began using it in his electrophysiological experiments. The ABR, currently the most popular AEP used in clinical contexts, was first described and defined by Jewett and Williston in the early 1970s (Glasscock *et al.,* 1987).

In 1963, the New York Academy of Arts and Sciences sponsored a symposium of investigators of averaged potentials (including visual, somatosensory, auditory, myogenic and neurogenic), followed by the founding of the International Electrical Response Audiometry study group in 1968 (Abramovich, 1990).

Much of the research in the field of AEPs tries to correlate the electrical responses with auditory behavioural thresholds. Reneau and Hnatiow (1975) cite difficulties in relating physiological thresholds (such as evoked responses) to behavioural response thresholds. It was believed that behavioural responses are binary measures in which a subject decides between “yes” or

"no", while physiological thresholds are graded, or quantitative, and that graded measures are mathematically different from binary ones. It was concluded that these two types of tests can be expected to yield different results. Nevertheless, as a result of subsequent advances in electronics, and a far greater understanding of brain function, there has been a move in the field of AEPs, supported in this study, to relate behavioural and physiological thresholds.

The enthusiasm for auditory evoked potentials in the 1970s resulted in this type of testing, being incorporated in test batteries for unco-operative patients such as small children (Martin, 1994). It is thus logical that the use of this quantitative procedure was also extended to cases of pseudohypacusis (Roeser *et al.*, 2000b).

As early as 1990, the use of auditory evoked potentials was recommended in the assessment of pseudohypacusic patients by Abramovich (1990), who also cites the use of slow vertical responses, auditory brain stem response, middle latency responses and transtympanic electrocochleograms as possible auditory evoked potentials to be used with pseudohypacusic patients. Today, a mere decade, later is it predicted that in future, AEPs will become even more prominent in the field of Audiology (Roeser, Buckley & Sichney, 2000).

3.2.2.3 Nomenclature and definitions

Picton and Scherg (1990) argue that one of the most important clinical applications of AEPs is their use in objectively evaluating the hearing of patients who are unable to respond during conventional testing. However, in order to evaluate this application, it is important first to define auditory evoked potentials and to highlight controversial issues.

Stach (1998:293) describes the measurement of AEPs as follows:

> The brain processes information by sending small electrical impulses from one nerve to another. This electrical activity can be recorded by placing sensing electrodes on the scalp and measuring the ongoing changes in electrical potentials throughout the brain. This technique is called electroencephalography, or EEG, and is the basis for recording evoked potentials. The passive monitoring of EEG activity reveals the brain in a constant state of activity; electrical potentials of various frequencies and amplitudes are measured continually. If a sound is introduced to the ear, the brain's response to that sound is just another of a vast number of electrical potentials that occur at that instant of time. Evoked potential measurement techniques are designed to extract these tiny signals from the ongoing electrical activity.

This described electrical activity can be spontaneous or event-related (Picton, 2001). Responses that are time-linked to some event or stimulus are called event-related potentials (ERPs), and can be responses to a sensory stimulus (such as a visible flash or a sound), a mental event, or the interruption, delay or omission of a stimulus (Picton, 2001).

Auditory evoked potentials (AEP) are a type of ERP in which the stimulus is a sound, and the response takes the form of very small electrical potentials originating in the nervous system and recorded at the scalp (Picton, 2001). AEPs originate from structures such as the auditory cortex, the auditory brainstem and the auditory cranial nerve (VIII or 8^{th}). These electrical potentials are very small: 2 to 10 micro volts for cortical AEPs, and less than one microvolt for deeper brainstem structures (Picton, 2001).

The measurement of these potentials in response to auditory stimuli has become a valuable diagnostic tool (Stach, 1998) but is still an evolving field in which there are problematic issues that need to be resolved.

3.2.2.4 Problematic issues in the field of AEP

It should be noted that the terms “evoked potential” and “evoked response” are used interchangeably in the literature (Hood, 1998). The term “response” is derived from the procedure of pure-tone audiometry in which a stimulus is presented and a response (motor action) is subsequently recorded. In AEP testing, a response is not recorded, but a potential is measured. Furthermore, electrical activity is elicited by a signal, and not a stimulus (Goldstein & Aldrich, 1999).

The term “stimulus” implies perception, but in tests of auditory brain stem response and auditory steady state response, electrical activity is measured sub cortically and only up to brainstem level. It should therefore be remembered that the terms “stimulus” and “signal” are interchangeable, as are “potential” and “response” (Schmulian, 2002).

The field of evoked potentials has been burdened with inconsistencies in terminology and definitions and its classification system has lacked uniformity and clarity (Ferraro & Durrant, 1994; Schmulian, 2002). Schmulian (2002) attributes this lack of clarity to the presence of specialists from the different fields of audiology, neurology and otolaryngology who all work in the field of evoked potentials. Classifications of AEPs in the literature can be divided into those based on anatomical generators, on the type of potential, on the types of stimuli used, on the location of recording electrodes and on latency characteristics (the time between stimulus onset and response) (Schmulian, 2002).

The most common classification of AEPs is based on their time domain (Goldstein & Aldrich, 1999), in which the time between the stimulus and the response is termed the “latency epoch”. Ferraro and Durrant (1994) mention that, although this classification system is the easiest to apply, the classification of latency is not standardised. A familiar method is to classify response latency as short, middle or late latency responses, depending on the

time between the presentation of the stimulus and the responses' becoming evident as an AEP. Short latency is referred to as "fast" by Glasscock *et al.* (1987), and as "early" by Abramovich (1990), while "late" latency responses are also referred to as "slow". These types of inconsistency create confusion.

Because latency varies according to stimulus intensity, temporal characteristics and pathology, it has been found that authors attribute different latency epochs to different AEPs. So, for example, according to Picton (2001), the ABR is seen 1.5 to 15 milliseconds (ms) after the stimulus, which contradicts Abramovich (1990), who states that an auditory brain stem response (ABR) is seen within the first 10 ms after the stimulus. Different nomenclatures are also used to identify major peaks for AEPs, for example Roman and Arabic numerals are used for ABR waves, and "No" or "SN10" are used to identify the slow negative wave appearing in the ABR after 10 ms.

3.2.2.5 The use of different potentials in pseudohypacusis

The use of auditory evoked potentials in the estimation of hearing in patients that cannot or will not co-operate during behavioural tests has been advocated by numerous authors (Abramovich, 1990; Mc Pherson & Starr, 1993; Stach, 1998). Schmulian (2002) expresses a stronger opinion, saying that AEP testing is the only procedure in the audiologists' test battery that can quantify the hearing sensitivity of unco-operative patients.

If an audiologist has to rely on a single test in a battery (due to an unco-operative patient), AEP testing needs to meet the following requirements (Roeser *et al*., 2000b):

- The test should diagnose the nature of the hearing loss (conductive or sensory neural).
- The degree of hearing loss (from normal hearing to profound hearing loss) has to be established.

- The configuration of the hearing loss (across a range from 250 to 8 000 Hz) is important clinical information and must be determined.
- Frequency-specific hearing thresholds need to be estimated for both ears.

The above requirements are used in the discussion below to evaluate the use of different auditory evoked potentials in pseudohypacusic patients.

3.2.2.5.1 Early potentials

The first three AEPs identified (cochlear microphonic (CM); action potential (AP) and summating potential (SP) are very early-stage potentials seen during the first 5 ms after stimulation with a sound (Stach, 1998). Responses to sound originate in the cochlea and the distal portion of the auditory nerve. They are also grouped together in clinical use as the electrocochleogram (EcochG). Tone burst and click stimuli are used to elicit responses, and two different electrode placements for near-field measurements are possible, namely

- transtympanic placement, where an electrode is invasively placed through the tympanic membrane onto the promontory of the temporal bone; and
- the external auditory meatus (EAM) near the tympanic membrane (Abramovich, 1990).

The value of the EcochG lies in its usefulness for assessing the hearing of young children who are difficult to control in clinical situations, and in the fact that these potentials are not altered by anaesthesia. The EcochG provides information on inner ear function (Abramovich, 1990) in conditions such as tinnitus, Meniere's disease and sudden hearing loss (Halliday, 1993). Its disadvantages are that low frequency function is almost impossible to assess, and the surgical procedures required for transtympanic placement make the EcochG invasive (Abramovich, 1990).

The use of electrocochleography in pseudohypacusic populations (Qiu *et al.,* 1998; Rintelmann *et al*., 1991; Abramovich, 1990*)* has been reported. Rintelmann and his co-authors opine that EcochG does not measure the ability to hear. The invasive nature of the surgical procedures for the EcochG and the resultant need for an Ear-, Nose- and Throat (ENT) specialist (Schmulian, 2002), together with the ability of the test to measure only the most peripheral functions of the auditory system limit its clinical use to a small number of highly specialised diagnostic centres (Abramovich, 1990; Stach, 1998).

It can be concluded that pseudohypacusic patients are not adequately evaluated by early potential testing, as it fails to include all of the frequencies required for compensation assessments, and the invasiveness of the procedure is unacceptable for Occupational Health applications.

3.2.2.5.2 ABR

ABR is a big misnomer in the field of AEPs (Schmulian, 2002). Since the ABR is the most widely used AEP (Hood, 1995), all AEPs have come to being perceived as ABRs, irrespective of the latency epoch and the equipment used (Goldstein & Aldrich, 1999). Ferraro and Durrant (1994) have found ten different names for ABRs in a literature review, including “brainstem auditory evoked potential”, “brainstem auditory evoked response”, and “auditory brainstem evoked response”, to list but a few.

In ABR testing, electrical potentials are generated by the VIII (8^{th}) cranial nerve and neural centres within the brainstem (Stach, 1998). The ABR uses far-field potentials recorded at the scalp (vertex), and comprises five or more waves generated in the auditory pathway up to the level of the inferior colliculus. The procedure is firmly established in clinical practice for estimating audiometric thresholds and for neurological/neuro-otological diagnosis (Abramovich, 1990). In South Africa, ABR has for many years been the test of choice among the available AEP procedures, particularly for

difficult-to-test patients for whom the configuration and severity of hearing loss have to be determined. The waves are robust and easily recorded, and are unaffected by the patient's state of consciousness (the patient can even be asleep or sedated).

ABR potentials are minute, rarely reaching amplitudes greater than 1 micro volt (µV), and thus it requires a great deal of averaging to distinguish potentials from background noise and other artefacts (Arnold, 2000). Furthermore, ABR tests rely on transient responses elicited by brief acoustic stimuli (Arnold, 2000), as the more abrupt the stimulus, the more clearly defined the ABR. The most widely used stimulus is a broadband click, because of its rapid onset (100 µsec) and broad frequency content, which stimulates a large portion of the basilar membrane to give a reasonable indication of hearing thresholds between 2 000 and 4 000 Hz. However, due to the structural and mechanical properties of the cochlea, ABR can only predict auditory sensitivity in the upper part of this range to within 5 to 20 dB of behavioural thresholds (Rance *et al.,* 1998). This limitation has led to the development of other stimuli, including tone bursts, filtered clicks and various masking techniques to provide more precise information on narrower frequency ranges (Hood, 1998).

According to Swanepoel (2001), tone bursts are the stimulus of choice where low frequency threshold information is required. Tone bursts are more frequency-specific than clicks, and their gradual stimulus onset ensures good frequency specificity (Weber, 1994). Unfortunately, the resulting stimulus does not elicit a clear ABR and, therefore, an abrupt stimulus onset is necessary to improve the quality of the response. However, this introduces high-frequency energy into the test stimulus, necessitating the use of masking techniques to eliminate the effects of unwanted high frequency energy. Stapells *et al.* (1990) have obtained good agreement between ABR and behavioural thresholds by using tone burst stimuli embedded in notched noise.

Unfortunately, the time needed to obtain a single ABR threshold for each ear exceeds 30 minutes, making a full audiogram impractical (Weber, 1994). With children the test often lasts for as long as the child sleeps and, even with adults, a long test is tiring and undesirable (Swanepoel, 2001). At the moment, the best method for determining hearing loss configuration is to present first a low-frequency tone burst and then a click ABR. This procedure is an attempt to shorten the procedure, but should still allow the audiologist to get an idea of the configuration of the hearing loss.

An advantage of ABR is that the latencies of the various waves are quite stable within and among different patients (Abramovich, 1990). In addition, time intervals between peaks are prolonged by auditory disorders central to the cochlea, making ABR useful in differentiating cochlear and retrocochlear pathology (Weber, 1994).

A disadvantage is that the interpretation of wave forms is subjective (Martin, 1994), and the interpretation of tone bursts requires considerable expertise and experience (Abramovich, 1990; Swanepoel, 2001). The ABR is also time-consuming, and the maximum stimulus level for clicks and tone bursts is restricted, resulting in a risk that the audiologist may fail to identify residual hearing at high loudness levels. Furthermore, the high cost of instrumentation and software are added negative considerations (Schmulian, 2002). Qiu *et al.* (1998) point out the further disadvantage that involuntary responses are generated only by sub-cortical structures and, hence, can never provide a measure of true hearing thresholds. These authors also criticise the great technical demands with regard to stimulus, filter settings, recording methods and response interpretation with bone-conduction ABRs. This limits the clinical application of the technique.

In a study by Barrs *et al.* (1994), it was found that an ABR was a useful procedure in the threshold confirmation needed in cases of noise-induced hearing loss, but that middle latency responses were more useful than the ABR because of the ABRs tendency to overestimate hearing loss in down-

sloping audiograms. Middle latency responses were also more frequency specific which is important in the case of noise-induced hearing loss evaluations.

From the preceding discussion, it is apparent that the ABR has up to now been the most widely used electrophysiological procedure, and is the only electrophysiological procedure prescribed in South Africa for the formal assessment of pseudohypacusic patients (RMA guidelines, 2003). Despite the limitations discussed above, frequency-specific threshold determinations are possible, but only through a long and expensive process requiring a great deal of skill and experience on the part of the audiologist. These are two important limitations that hinder the consistent use of ABRs in hearing assessment in the mining industry.

3.2.2.5.3 Middle latency responses

It is generally accepted that there are two main reasons for the use of auditory electrophysiological tests, namely the need to make inferences regarding hearing thresholds and the need to obtain information regarding the functional and structural integrity of the auditory pathway's neural components (Kraus, Kileny & McGee, 1994). The purpose of this section is to provide a basis for understanding the principles and applications of middle latency response (MLR) testing and to evaluate the contribution of MLRs in meeting the above two aims.

An MLR is a series of waveforms occurring 10 to 80 ms after the onset of an auditory stimulus (Kraus *et al*., 1994). Here, again, contradictory classifications abound in the literature. Abramovich (1990) classifies MLR as having a latency of 8 to 50 ms, while Picton (2001) and Glasscock *et al*. (1987) set latency at 25 to 50 and 12 to 50 ms respectively. Within the continuum of components comprising scalp-recorded AEPs, MLRs follow ABRs and precede late latency responses (LLRs), while evoked potentials No, Po, Na, Pa, Nb and Pb are classified as MLRs (Kraus *et al*., 1994).

According to Kraus *et al.* (1994), Geisler and his co-workers were the first investigators to describe MLRs (in 1958). MLRs are measured at the scalp, using an electrode montage identical to that used for ABR recordings, and MLR generators include many brain structures central to the midbrain, as well as structures outside the primary auditory pathway, such as the auditory thalamocortical pathway, the reticular formation and the multi-sensory divisions of the thalamus (Kraus *et al.,* 1994).

MLR is used clinically for electrophysiological determination of hearing thresholds at lower frequencies, for the assessment of cochlear implants and auditory pathway function, and for the localisation of auditory pathway lesions. They are also used intra-operatively (McPherson & Ballachanda, 2000). It is thus clear that MLR has many applications in audiology, but unfortunately, the disadvantages of MLRs overshadow the advantages.

The most important limitations include:

- the inconsistency of responses as specifically observed in the paediatric population (Kraus *et al*., 1994);
- highly specialised equipment requirements (Schmulian, 2002), including EEG for example;
- the need for the patient to be awake, co-operative and alert (Hood, 1995). Ferraro and Durant (1994) state that sensitivity to the patient's state of consciousness limits the acceptance of MLR techniques; Thorton *et al.* (1984) show that MLRs are distorted and delayed during sedation, and those potentials are poorly detected in stage IV sleep;
- a perception that MLRs are not considered a mainstream electrophysiological test (Mc Pherson & Ballachanda, 2000), and are regarded as difficult to record (Abramovich, 1990), causing a lack of facilities where these procedures could be tested; and

- reports that MLR potentials can be contaminated by muscle potentials from the neck or peri-auricular region (McPherson & Ballachanda, 2000).

The question that needs to be answered is whether MLRs can be used as a technique to identify pseudohypacusic mine workers and quantify their hearing loss. Abramovich, (1990) advocates the use of MLRs in pseudohypacusic patients. He is of the opinion that a stimulation rate of 40 per second instead of the usual 10 per second can cause a superimposition of the peaks of MLRs and an augmentation of the response. He specifies that MLRs are to be used in this population when slow vertical response (SVR) measurement conditions are poor. Barrs *et al*. (1994) mention the possibility of using MLRs to detect work–related noise-induced hearing loss, stating that MLRs are more effective in threshold estimation than ABRs, as a result of the steepness of the audiometric curve in noise-induced hearing loss. Barrs *et al*. (1994) also advocate the use of MLRs to verify low frequency thresholds.

McPherson and Ballachanda (2000) argue that the biggest problem in testing and verifying these MLRs is the fact that these evoked potentials are not considered to be mainstream electrophysiological tests in audiology practice. Hence, equipment and facilities are not readily available.

3.2.2.5.4 Late latency responses (LLR)

As indicated previously, confusing nomenclature also exists regarding the potentials evoked at later latencies. These potentials are described as “slow” (Halliday, 1993), while Stach (1998) favours the term “late latency response” (LLR). “Slow vertical response” (Abranovich, 1990) and “cortically evoked responses” (Rickards *et al*., 1996) are other nomenclature in the existing literature. The confusing nomenclature stated above is further compounded by a lack in uniformity in the latency epochs of LLRs. Ferraro and Durrant (1994) define LLRs as potentials manifesting 50 to 800 ms after the stimulus, while Glasscock *et al.* (1987) and Picton (1991) relate latencies in this sub-class to 250 to 600 and 50 to 200 ms, respectively.

These potentials have been found to be greatly affected by subject state (Abramovich, 1990; Stach, 1998), and the potentials are best recorded when the patient is awake and attending carefully to the sounds presented. It is thus understandable that these methods are only used in adult, difficult-to-test populations. Stach (1998) mentions that LLRs are robust and easily recorded in adults and that the response can estimate auditory sensitivity independently of behavioural response.

As is the case with other potentials, the late latency response generators are still unknown. Halliday (1993) attributes the P3 or P300 AEP to widespread activity of the frontal cortex involving the parietal association areas.

An important disadvantage of LLRs is the fact that the procedure is time-consuming. Abramovich (1990) estimates the time requirement for four thresholds in two ears at 60 minutes.

With regard to the application of late latency responses to the pseudohypacusic population, it is worth noting that several authors have promoted LLRs as a medico-legal test (Halliday, 1993; Rickards *et al.,* 1996; Rickards & De Vidi, 1995; Abramovich, 1990; Dobie, 2001; McCandless & Lentz, 1968; Hyde *et al*., 1986; Coles & Mason, 1984).

As early as 1968 McCandless and Lentz tested LLRs on adults with pseudohypacusis using pure-tone stimuli with a 700 msec duration. They found a very good correlation between the electrophysiological and behavioural thresholds (5dB).

Abramovich (1990) claims that SVR testing is the test of choice for assessing non-organic hearing loss. He argues that SVRs most closely approximates the results of conventional frequency-specific audiometry (within 10 dB), and that SVR is insensitive to neurological dysfunction. Pseudohypacusic patients are instructed to pay attention, and those who deliberately exaggerate their level of attention due to anxiety can be clearly identified. The stimulus used is a 100 ms tone burst with rise and fall times of 10 ms.

Coles and Mason (1984) used a 50 to 300 ms latency epoch and have proven that these latency responses have by far the greatest value for verifying pure-tone thresholds in adult patients, in comparison to brainstem and cochlear potentials. The tonal signals that these authors used had a duration of 200 ms and a rise and fall time of 10 ms. A specific advantage of LLRs mentioned by these researchers is the frequency specificity at low frequencies where non-organic overlay is maximal. They also argue for the use of LLRs in medico-legal investigations because of the non-invasive nature of the procedure and because the procedure tests up to a much higher dB level than, for instance, the ABR. Hence, there is a less likelihood of a non-peripheral disorder causing a discrepancy between the AEP and the behavioural threshold.

Hyde *et al*. (1986) have expressed the opinion that the verification of pure-tone audiometry is a long-standing problem in Departments of Veterans' administration, compensation assessment for noise-induced hearing loss and medico-legal evaluation. These authors have found a correlation between the slow vertical response and behavioural thresholds of within 10 dB. The stimuli used are tone bursts with 10 ms rise and fall times, and a 40 ms plateau. Despite a very good threshold estimation ability, and although by 1986 the procedure had been used in the Mount Sinai hospital (Toronto), for a decade, the authors emphasise the following disadvantages of using SVRs:

- testers in a clinical setting need to be experienced and carefully trained audiologists whose performance is monitored (it is clear that the skill requirement is very high);
- the test procedure is demanding and the skill requirements are often underestimated;
- testers need to have an adequate caseload to maintain their skill;
- all clinical interpretation is subjective and on-line;
- slow vertex response audiometry is problematic in 5 per cent of cases due to high levels of rhythmic activity:

- the time exceeds 1.5 hours in 95 per cent of cases (Hyde *et al.,* 1986);
- from the above it is clear there is still a limited acceptance of the technique even in North America (Hyde *et al.,* 1986; Dobie, 2001).

Picton (2001) indicates that the British Columbia Workers Compensation Board has used LLRs, and Rickards *et al*. (1996) state that cortical evoked response audiometry (CERA) has been used to assess noise-induced hearing loss in the Australian state of Victoria for the past 15 years, with 18 per cent of all noise-induced hearing loss cases referred for CERA. This seems to indicate some positive experience with AEP procedures.

CERA thresholds have been found to be within 10 dB of pure-tone thresholds, but, again, the procedure has failed to gain wide acceptance. Rickards *et al*. (1996) indicate that reliance on subjective interpretations of tracings, and the high levels of skill and training required of testers have hampered acceptance of CERA as a routine test for pseudohypacusis.

As far as can be determined, late latency responses have not so far been used in South Africa for the assessment of noise-induced hearing loss or the evaluation of compensation claims. Although it is clear that, as in any clinical population, no single AEP method is always the best (Hyde *et al.,* 1986), the main reason for searching for a better method is a lack of objectivity in deciding whether the evoked potential is present.

3.3 SUMMARY

This chapter has discussed electrophysiological tests, particularly AEPs, as a possible means of determining accurate hearing thresholds for pseudohypacusic mine workers. Nomenclature, selected definitions and the historic evolution of AEPs have also been discussed, and the value of various AEP methods for estimating hearing thresholds have been examined.

A summary of the disadvantages of currently used AEPs based on the above discussion, is set out in Table 3.1 below.

TABLE 3.1: DISADVANTAGES OF AEPs

Type of AEP	Special equipment	expensive	time consuming	age sensitive	influenced by neural dysfunction	state dependant	subjective interpretation	not frequency specific	sub cortical	invasive	skilled tester
ECochG	✕	✕	✕		✕		✕	✕	✕	✕	✕
ABR	✕	✕	✕	✕	✕		✕	✕	✕		✕
MLRs	✕	✕	✕	✕	✕	✕	✕		✕		✕
LLRs	✕	✕	✕	✕		✕	✕				✕

Although LLRs have been used internationally in medico-legal evaluations, an even better solution is still sought for. A recent development in the field of AEPs is auditory steady state responses (ASSRs), which is discussed comprehensively in the next chapter. Lins *et al.* (1995) have found that results obtained from ASSR testing can be presented as an audiogram, thereby providing information about the extent, nature and configuration of hearing loss. Most importantly, it has been reported that ASSR provides true objectivity, as thresholds are not determined subjectively, through a clinician's interpretation of wave forms, as is the case with ABR and LLRs, but are rather calculated objectively by a computer (ERA systems Pty. Ltd, 2000).

The latter crucial benefit motivated this researcher to investigate this type of AEP as a possible means for testing pseudohypacusic patients, particularly those with noise-induced hearing loss in the South African mining industry.

CHAPTER 4

AUDITORY STEADY STATE RESPONSES (ASSR) AND PSEUDOHYPACUSIS

AIM

To critically evaluate and describe a specific, auditory evoked potential, the auditory steady state response, as a frequency-specific threshold estimation procedure for use in certain difficult-to-test-populations. A motivation for the use particularly in pseudohypacusic populations with suspected noise-induced hearing loss is also given.

4.1 INTRODUCTION

In seeking a truly objective hearing threshold estimation technique for difficult-to-test populations, the emphasis worldwide has been on auditory evoked potentials. Hence, this was the main focus in the previous chapter.

The ultimate goal of an objective threshold estimation technique is to establish an audiogram in a frequency-specific manner without any need for voluntary responses from the subject (Picton, 1991; Aoyagi *et al.,* 1994). One aspect of objectivity that is not addressed in this criterion is that of the clinician's perception, experience and skill in detecting the appropriate wave form during AEP tests. This suggests that subjectivity persists in the decision of whether or not an evoked potential is present.

Rance *et al.* (1995) point out that ASSRs can be detected automatically, excluding the subjective evaluation, through real-time statistical analysis of samples from the response phase using a digital computer. This statement needs to be qualified somewhat, in that real-time statistical analysis has to be directed by research in that an appropriate clinical test set-up, noise floor determinants, number of averages and sweeps need to be standardised

(especially to make comparisons between research studies more meaningful). Provided that this final component of objectivity is addressed, it is possible to use electrophysiological measures to assess patients who cannot or will not co-operate with conventional hearing test procedures (Sininger & Cone-Wesson, 2002).

Auditory steady state responses are discussed in this present chapter as a possible means to determine frequency-specific hearing thresholds estimates for pseudohypacusic patients, without any need for the subjective detection of responses on the part of a clinician. The discussion below defines and contextualises ASSRs. The stimulus parameters used to elicit responses are addressed. The chapter concludes with the limitations and advantages of this technique with specific reference to its application to pseudohypacusic workers. This theoretical study of ASSRs has formed the basis for a research programme (see Chapter 5) to evaluate their clinical value in a population of South African mine workers with noise-induced hearing loss and possible pseudohypacusis.

4.2 THE DEVELOPMENT OF AUDITORY STEADY STATE RESPONSES

Auditory steady state responses and steady state evoked potentials (SSEPs) are the two most frequently used labels found in a survey of relevant literature to describe this "new" type of AEP. Other, less frequently used, terms are "steady state fields" (Pantev *et al.,* 1996), "frequency following response" (Kuwada *et al.,* 1986) and "envelope following response" (Dolphin & Mountain, 1993). Although there are some differences in their applications, the definitions of these terms boil down to more or less the same concept. The term ASSR and SSEP are commonly used interchangeably, but, Sininger and Cone-Wesson (2002) have concluded that ASSR has become the term of choice in recent years. This assessment can, however, not be accepted without a critical analysis of the uses and implications of the term ASSR as

the name for a new auditory evoked potential. Such an analysis is provided below.

Critics of the term “response” argue that in conventional audiometry, this term is applied to instances where the patient reacts to a stimulus that is presented in the form of a sound. Schmulian (2002) also questions the use of the term “response” in relation to evoked potential methods, since electrical waves are measured without any regard to a conscious or voluntary response on the part of the subject (Goldstein & Aldrich, 1999). Notwithstanding this discrepancy, it seems that the use of the term ASSR has gained wide acceptance and it is therefore used in the rest of this study. In a clinical context, the term “response” would certainly be acceptable, as protocols are designed and recorded to establish a response, for example, at the threshold level.

The AEP technique known as ASSR was discovered and developed at the University of Melbourne during the 1980s (ERA Systems Pty Ltd, 2000). This clinical test system was preceded by research on human steady-state evoked potentials in the visual field (Picton *et al.*, 2003). Galambos, Makerg and Talmachoff’s (1981) research provided the main impetus for extensive research into auditory steady state responses (Picton *et al.*, 2003). Rance *et. al.* (1995) and Rance *et al.,* (1998) indicate that ASSRs address the main shortcomings of ABR testing, in that ASSR is an alternative frequency-specific approach which does not suffer the spectral distortion problems associated with short-duration stimuli. ASSRs are periodic scalp potentials arising in response to regularly varying stimuli, such as a sinusoidal amplitude- and/or frequency-modulated tones (Rance *et. al.,* 1998).

ASSRs could be conceptualised as follows:

> Imagine the waveform for an evoked response which is displayed as a waveform in the time domain. Imagine the waveform for an evoked response if two tone burst stimuli were presented within an averaging epoch. Each tone burst would be expected to produce a response, and

> so the response waveform would be repeated twice, within the averaged epoch. Now imagine a 200 ms train of 2-1-2 cycle tone bursts, say at 1000 Hz, with an inter stimulus interval between each burst of 20 ms. Imagine that the signal-averaging epoch is also 200 ms in duration. One thousand 200-ms trains are presented and the response to each train is averaged. There are 10 responses in the time-averaged waveform for the 200-ms sample. Since the recorded response is periodic it can be analysed using frequency domain methods. To summarise: steady state responses are recorded when stimuli are presented periodically and they demonstrate how the brain reacts to a stimulus (Picton *et al.*, 2003)

From this description it can be seen that ASSRs are evoked by stimuli in the form of rapidly changing auditory signals, presented at such a high rate as to cause overlapping of responses. This yields what is effectively a steady state response to a sustained sound or continuous stimuli, as opposed to a transient response to changing auditory stimuli (Stapells, *et al.,* 1984).

ASSR techniques also use various protocols to evaluate the presence of a response. Transient responses like ABRs are usually described in terms of the latencies and the amplitude of specific waves. Latency can be explained as the time interval between the stimulus onset and the peak of a waveform. In the case of an ABR, the latency of wave I is for instance, 1,6 ms after stimulus onset (Hood, 1998). ASSRs by contrast, are not measured in the time domain (between the stimulus and the response), but in the frequency domain. Lins *et al*. (1996) explain that the compound electrical activity recordings contain the spectral component for the rate of modulation at which the tone is presented. Thus the stimulus drives the response to reflect the same amplitude and frequency modulation with which the stimulus was presented (Picton *et al.*, 2003).

Human steady state responses were initially studied in the field of visual modality (Stapells *et al*., 1984; Picton & Scherg, 1990). A description of the auditory steady state response by Galambos *et al.* (1981) reawakened interest in the phenomenon and its possible use in objective threshold

estimation (Picton *et al.,* 1987). It was shown that when stimuli are presented at a rate of 40 per second, the middle latency responses have an amplitude some two to three times greater than when stimuli are presented at the conventional rate of 10 per second. (Stapells *et al.*, 1984). Unfortunately, the 40 Hz response has proved to be unreliable for young infants, so clinicians turned to stimulation rates of 80 to 100 Hz, as they are less affected by sleep, maturation and sedation (Rance *et al.,* 1995; Herdman & Stapells, 2001; John, Dimitrijevic & Picton, 2002).

A recent ASSR development is the multiple-frequency technique, where several carrier frequencies are presented to both ears simultaneously (Lins & Picton, 1995; John, Dimitrijevic & Picton, 2001b). The purpose of this procedure is to shorten test time, which is a critical requirement in clinical practice, particularly in the case of difficult-to-test patients and infants, who often do not remain asleep long enough for the test to be completed.

In recent years, the stimuli used in ASSR testing have also been manipulated. Initially, the pure-tone was only amplitude modulated (John & Picton, 2000; Cohen, Rickards & Clark, 1991), but later developments showed that tones modulated in terms of both frequency and amplitude (mixed modulation) give improved threshold estimates (Dimitrijevic *et al*., 2001).

From the above it is clear that the ASSR technique has virtually exploded in the last five years within the AEP context. The initial findings were promising, but limited due to maturational and wakefulness effects, it was relegated to more of a research endeavour (Schmulian, 2002). Thus far, ASSRs have been tested mainly on normal hearing subjects and on very small samples. Difficult-to-test populations examined have included mainly babies and young children (Sininger & Cone-Wesson, 1994; Savio *et al.,* 2001; Aoyagi *et al*., 1996; Rance *et al.* 1998). No studies on adult pseudohypacusic populations could be found.

The fact that the technique has been used in babies (always a difficult-to-test population) and since “automated response detection” brings an extra dimension of objectivity to the evaluation of difficult-to-test populations motivated an attempt to evaluate this technique for use in an adult pseudohypacusic population.

Relevant testing parameters and previous research findings related to ASSRs were evaluated in Section 4.3 to obtain guidelines for an experimental design.

4.3 RESEARCH FINDINGS WITH ASSRs

4.3.1 TYPES OF STIMULI

One of the key differences between ASSR techniques and other AEP methods are in the stimuli used, as discussed below.

Rob *et al.* (2000) list the various stimuli used in ASSR testing as click trains, trains of short tone-bursts and modulated tones. Modulated tones are the most widely used stimuli for eliciting steady state responses, because tones are continuous and, hence, are not affected by the spectral distortion problems associated with brief tone bursts or clicks (Rance *et al*., 1995). As has been demonstrated in the previous chapter, tone bursts and clicks have been used in ABR testing with pseudohypacusic patients, but these stimuli have not been frequency-specific enough. In medico-legal evaluations (such as mine workers with noise-induced hearing loss) the availability of frequency-specific threshold estimates at all the legally specified frequencies are of the utmost importance and thus the use of tones with longer rise and fall times is promising with regard to achieving frequency-specificity with pseudohypacusic adults.

4.3.2 STIMULUS INTENSITY

The speed at which thresholds can be determined with this technique depends in part on the amplitude of the ASSR, as the response must be

distinguished from background noise. The greater the response's amplitude, the more rapid detection is. Nevertheless, research has shown that ASSRs can be recorded at low sensation levels (Dobie & Wilson, 1998). Rance *et al.* (1995) have found that ASSRs could be recorded at low sensation levels even with patients who are sleeping or sedated, provided that the modulation frequency is greater than 70 Hz.

Schmulian (2002) has also discussed the influence of intensity on multiple frequency (MF)-ASSR techniques, saying that at low-to-moderate intensity levels, the responses elicited with different carrier frequencies (CFs) show little overlap, provided CFs are one octave apart to ensure that effects on the basilar membrane occur at different locations. At higher intensities, the basal end of the cochlea tends to dominate, causing significant overlap to occur- hence, frequency-specific responses are more difficult to detect.

Low intensity MF-stimulation is particularly important in a population of mine workers, since noise-induced hearing loss is usually a sloping hearing loss with thresholds at 500 and 1000 Hz, near normal levels (Dobie, 2001).

4.3.3 CARRIER FREQUENCY

The effects of carrier frequency are quite different for stimuli modulated at rates of 40 to 80 Hz (Picton *et al.*, 2003). The 40 Hz responses significantly decrease in amplitude with increasing carrier frequency (Galambos *et al.,* 1981). For the 80 to 100 Hz responses, the amplitude is larger for the middle frequencies (1000 to 2000 Hz) than for either higher or lower frequencies (Picton *et al.*, 2003). Some of this effect at 80 Hz MF-techniques might be due to the fact that the stimuli at different CFs are presented at the same sound pressure level (normal hearing thresholds are found at lower frequencies).

It has been proven that the higher the carrier frequency and the greater the hearing loss, the better the correlation between ASSR and pure-tone

thresholds is (Sininger & Cone-Wesson, 1994; Rance *et al*., 1995). This fact could be due to recruitment when monotic procedures are used.

John and Picton (2000) found that the latency of human ASSRs to amplitude modulated (AM) tones changes significantly and consistently with the carrier frequency in a MF-stimulation procedure. Latency periods are shorter for higher frequencies (for example, latency reduced from 6,0 to 5,5 ms when the CF was increased from 500 to 6 000 Hz). Such changes in the latency period appear to result from two cochlear processes: the filter build-up time of the hair cell transduction process and the transport time for acoustic energy to reach the responsive region of the basilar membrane, which is at the apex of the cochlea for low-frequency stimuli.

Schmulian (2002) explains that the lower amplitude of responses observed when a low CF is used is due to the fact that the activation pattern on the basilar membrane extends over a greater area than is the case with higher carrier frequencies. This causes a “jitter”, which could attenuate the amplitude of the response. The intrinsic jitter at 500 Hz has also been attributed to neural asynchrony (Lins *et al*., 1996). Other researchers have also discussed diminished responses at 500 Hz (John & Picton, 2000; Perez-Abalo *et al.,* 2001; Lins *et al.,* 1996; Aoyagi *et al*., 1994). One explanation attributed this lower amplitude of responses at lower CFs to a possible effect of ambient noise on stimuli at these frequencies (Lins *et al.,* 1996).

In the evaluation of this technique in a population of mine workers, it is important to note that 500 Hz is a frequency that must be tested by law (RMA guidelines, 2003) and thus it is important that accurate threshold estimates should be obtained at 500 Hz. One way of addressing the problems that various researchers have experienced in testing at 500 Hz is to limit the masking effect of ambient noise, in other words, to test in a sound-proof booth (Herdman & Stapells, 2001). In the clinical situation this should not imply any extra cost, since an acoustic booth is already used for conventional audiometry.

4.3.4 MODULATION FREQUENCY

With AEP methods, such as tone burst ABR, stimuli can evoke a response, but the latency, amplitude and threshold of the ABR are all affected by the stimulus level, rise-time and rate of presentation. Conventional signal averaging is used to detect the response, which is displayed as a wave form in the time-domain (Sininger & Cone-Wesson, 1994). This wave form needs to be identified by the clinician.

By contrast, ASSRs are periodic and can therefore be analysed by means of frequency domain methods. The spectrum of the response shows a major component at the rate at which the tone or stimulus is repeated or modulated and at the second harmonic of that frequency. It is thus clear that a response follows the same modulation rate as the stimulus and therefore the response detection is much more objective. It should be noted that with high modulation frequencies (for example, 100 Hz), each modulation has a 10 ms duration, with a 5 ms sinusoidally ramped rise-fall time and no plateau. The spectrum of the response peaks at the modulation frequency, thus determining the response's amplitude and phase characteristics, with no contamination of the response spectrum by the stimulus (Sininger & Cone-Wesson, 1994; John *et al*., 2002).

Not only is the frequency of the stimulus modulated, but the CF amplitude modulation introduces a replicable stimulus parameter, allowing a reliable estimation of hearing thresholds across the normal audiological test range, based on research on a wide range of modulation frequencies (4 to 450 Hz) (Cohen *et al.,* 1991). The success of amplitude modulation can be attributed to spectral power being present only at the CF and at two side bands (John *et al.,* 2002). This fact that it is possible to estimate behavioural thresholds across the audiological test range opens up the possibility that the degree and nature of hearing loss can now be determined in difficult-to-test populations. In fact, it has made this research possible.

Galambos *et al. (*1981) has described the initially popular modulation rate of 40 Hz, for which large and defined response amplitudes have been observed. One disadvantage of using the 40 Hz response is that at lower modulation frequencies such as 40Hz, responses have proven to be problematic, in that threshold estimation is affected by state of consciousness and sleep (Herdman & Stapells, 2001; Maiste & Picton, 1989; Lins et. al., 1995), maturation (Lins *et al.,* 1995) and anaesthesia (Plourde & Picton, 1990). As the modulation frequency is reduced, the principal site of evoked potential responses is likely to move up the auditory pathway, thereby increasing the latency period. Such effects were to be expected, given the sensitivity of response generators in the auditory cortical and lemniscal brainstem to a person's state of consciousness. Nevertheless, some researchers have proven that the 40 Hz response is a very effective means of threshold estimation, including John and Picton (2000), who maintain that 40 and 80 Hz are the most suitable modulation frequencies for threshold estimation. Unfortunately, the 40 Hz response is not reliable in young infants and children, due to maturation effects and the effect of state of consciousness, as mentioned above.

Dobie and Wilson (1998) state that ASSRs for adult patients are best recorded at low intensities in the alert/awake state, based on reduced 40 Hz responses among sleeping or sedated adults. They conclude that the 40 Hz response at low intensity levels is optimal for both alert and sedated adults. In sedated subjects, the reduced background noise made responses more detectable.

Due to the above difficulties with the 40 Hz response, a greater interest in the use of high repetition rates arose after it was found that they increased the amplitude of responses (Rickards & Clark, 1984). Modulation rates of 75 to 110 Hz were seen to be the most suitable for threshold estimation (Cohen *et al.*, 1991; Lins & Picton, 1995; Lins *et. al*., 1996). Lins *et al.* (1996) have demonstrated that modulation rates of 75 to 110 Hz can be used to estimate pure-tone thresholds to within 10 to 20 dB in sleeping babies and in normal

and hearing-impaired adults. Lins and Picton (1995) have reported that a modulation frequency of 80 Hz gives response latencies that are similar during sleep and wakefulness. A rate of 80 Hz has also been regarded as an effective modulation frequency for sedated adults (Dobie & Wilson, 1998). Higher modulation rates (770 Hz) have also proven to be effective in estimating hearing thresholds when they are used at low intensities (Clark *et al.,* 1991). In terms of the available equipment, the 40 Hz and 80 to 110 Hz are the most popular modulation frequencies at this stage.

The focus of the preceding discussion is amplitude modulation. However, Cohen *et al.* (1991) have found that frequency- and amplitude-modulated tones (AM/FM) yield larger response amplitudes that amplitude modulated tones alone, because additional processing channels are associated with frequency modulation and AM/FM tones excite a larger portion of the basilar membrane. This combined amplitude and frequency modulation is also called multiple modulation (MM) (Schmulian, 2002), and produces tones that sound similar to the warble tone used in paediatric audiology. John and Picton (2000) have found that responses elicited using both amplitude and frequency modulation reaches significance at twice the speed of tones that are only amplitude modulated.

Since different modulation frequencies have been shown to be successful in different populations, one can conclude that it is important to evaluate both a lower (40 Hz) and a higher modulation frequency (80 to 110 Hz) in an untested pseudohypacusic adult population, and to use mixed modulation in an experimental design, since it has already been proven to be more accurate in threshold estimation than amplitude or frequency modulation alone.

4.3.5 DICHOTIC STIMULATION

The above discussion of ASSR stimulus parameters has focused on monotic stimulus presentation, in which each frequency is assessed separately for each ear. Monotic presentation techniques were developed for hearing

assessments in cochlear implant programmes, because dichotic presentation limits the separation of responses at high intensities, which are quickly reached during evaluations of cochlear implant candidates with limited residual hearing (Rickards *et al.,* 1994).

An optimised variant of ASSRs called multiple simultaneous amplitude modulation has been described by Lins and Picton (1995). Distinct modulation rates (separated by more than one octave) are used for eight carrier tones (four per ear), and the modulated tones are combined to produce an acoustic stimulus capable of simultaneously activating different regions of the cochlea (Perez-Abalo *et al*., 2001). Herdman and Stapells (2001) have found that MF-ASSR testing of both ears produces responses comparable to the use of only one carrier frequency or four carrier frequencies to a single ear. It is claimed that the technique can predict eight thresholds in the time it takes to observe one single threshold (Lins *et al.,* 1996; Perez-Abalo *et al.,* 2001).

The MF-ASSR technique is also a variant of the 75 to 110 Hz ASSR that Perez-Abalo *et al. (*2001) have found to be reliable in predicting behavioural thresholds, with 80,9 per cent of ASSR and behavioural thresholds within 20 dB of each other. Similar results were reported by Herdman and Stapells (2001) with 87 per cent of ASSR and behavioural thresholds within 20 dB of each other.

There is an urgent need for techniques that will enable audiologists to determine behavioural thresholds in a time-efficient manner. An ASSR test time of 164 minutes for eight separately determined frequencies and a corresponding time of 83 minutes for multiple dichotic ASSR testing have been reported (Herdman & Stapells, 2001). Although 83 minutes is shorter, this is still impractical for clinical applications, especially for difficult-to-test patients. This is true even for a test time of 21 minutes, as reported for normal hearing subjects (Perez-Abalo *et al.,* 2001).

Swanepoel (2001) maintains that MF-ASSR techniques show great promise as a threshold estimation technique for patients of all ages, but, clinical validation is limited (see Section 4.3.6). It has thus been postulated that the technique cannot be considered for clinical use until additional studies have optimised parameters (John *et al.,* 2001b). Furthermore, Schmulian (2002) has pointed out that studies thus far have only used normal adults, well infants and a very limited (small) number of hearing-impaired subjects.

An exciting topic for future study is indicated by John *et al*. (1998) , who point out that everyday sounds contain multiple frequencies and, that therefore, the results of MF-ASSR methods may be more representative of actual hearing than those of tests using discrete stimuli.

Finally, the mere fact that simultaneous testing of eight frequencies is possible is an important advantage in a difficult-to-test population and in an industry (mining) that produces very high case loads. This is another (important) motivation for validating the technique in a mining environment.

4.3.6 LIMITED CLINICAL VALIDATION

In 2001, Swanepoel commented that ASSRs had not been studied very extensively. This is still the case, as no literature could be obtained pertaining to ASSRs and to noise-induced hearing loss and pseudohypacusis, which constitute the focus of the present study. When experimental testing began in September 2002, only one ASSR system was available at the University of Pretoria. As indicated before, clinical applications of ASSRs are in their infancy , and relevant research findings are limited (Schmulian, 2002).

The above debate will be illuminated further because the clinical validation of MF-ASSR is particularly limited for hearing-impaired subjects (Perez-Abalo *et al.,* 2001). Schmulian (2002) quotes six MF-ASSR studies in which no findings are reported regarding the possible impact of ASSR on an impaired auditory system. The present author would add that ASSR research is

characterised thus far by very small experimental groups. Johnson and Brown (2001) used only ten subjects, and Valdez *et al.* (1997) used only 16. The limited clinical validation and research is a confounding factor to the present research, since there are no similar studies available to which results can be compared to. In that sense then, this study is exploratory in nature.

4.3.7 LENGTH OF PROCEDURES

One disadvantage of AEP techniques, mentioned before, is the length of test procedures. ABR, the most popular AEP method, also presents this limitation in evaluating difficult-to-test patients (Stach, 1998). John *et al.* (2001a+b) report that, particularly with children, the examiner must obtain as much information as possible in the shortest possible time.

A positive factor is that continuing research has led to newer developments that reduce the time required for threshold determinations. The amplitude of the response limits the speed of threshold determination, as responses must be distinguished from background noise, indicating that it would be advantageous to increase response amplitude (John *et al*., 2002). Techniques that have already increased the speed of determination include the following:

- the use of multiple modulated (amplitude and frequency) stimuli for more rapid determination of thresholds than with simple amplitude modulation or frequency modulation of stimuli (John *et al.,* 2001b);
- amplitude modulation of stimuli using exponential envelopes can reduce the average test time by up to 21 minutes (Perez-Abalo *et al.,* 2001). This was achieved by increasing ASSR amplitude and latency, to reduce the time needed for responses to become significant (John *et al.,* 2002);
- evaluation of responses to several (eight) simultaneously presented amplitude-modulated (at different rates) stimuli (Lins & Picton , 1995) can reduce test time by allowing eight frequencies to be assessed

simultaneously. (This is in contrast with the more time-consuming separate assessment of individual frequencies in single carrier frequency tests (Herdman & Stapells, 2001; Perez-Abalo *et al.,* 2001). However, John *et al. (*2001b) postulate that MF-ASSR testing is not yet suitable for clinical applications, saying that more trials are needed to optimise stimulus and recording parameters before this procedure can be validated); and

- the use of analysis algorithms to automatically conclude stimulation and sampling once a predetermined probability value (for example P<0, 3) is achieved, thereby minimising test time for any given trial (ERA systems Pty Ltd, 2000).

Lengthy testing time can be seen as a negative factor when testing pseudohypacusic mine workers with ASSRs, since the mining industry produces very large case loads. A further negative influence of testing time is the impossibility of evaluating different test protocols with the same subject (De Koker, 2003).

4.3.8 SUBJECT-RELATED FACTORS

In recording AEPs and ASSRs, it is important to consider that a subject may induce inaccurate recordings by interfering with procedures or the test environment (Aoyagi *et al*., 1994; Schmulian, 2002). Body movement, tenseness and an inability to follow instructions or remain still create excessive background noise and have a negative effect on the quality of data collected (Sininger & Cone-Wesson, 1994). The same authors have recommended that the clinician optimises the amplitude of the response and minimises background noise to ensure quality recordings:

- a correct placement of electrodes improves recordings;
- adequate epoch duration is important;
- a suitable filter bandwidth should be selected;
- minimal electrical noise should be present;

- a sufficient number of sweeps is needed to yield reliable averages; and
- accommodation for the patient's age and state of consciousness should be made.

Because factors such as filter bandwidth, epoch duration and the number of sweeps averaged are controlled by computer software using algorithms developed during research, the clinicians main concern should be to control artefacts and background noise. Clinician's should also be aware of the need for a quiet test environment during ASSR threshold estimates, according to Herdman & Stapells (2001), who have found that the accuracy of threshold estimates improved by 5 to 10 dB when tests were conducted in an acoustically treated test booth. Subjects should be relaxed to minimise artefacts (John & Picton, 2000), and the head should be positioned for a relaxed posture to reduce peri-auricular and muscle potentials (Halliday, 1993). Dobie and Wilson (1998) recommend that patients be tested in a supine position, and in a darkened room.

Sedation is sometimes administered to ensure low noise levels, but this practice has medico-legal and ethical implications. Furthermore, patients must give informed consent before such a procedure is performed and medical support must be available. The latter aspect has financial implications. This statement paints a negative picture but, on the positive side**,** John and Picton (2000) observe that it is possible that, as researchers' experience with ASSR methods increased, inter-subject variance may diminish.

Since there are no previous data available on the adult difficult-to-test population of pseudohypacusic mine workers, it is important to verify if sedation will influence the accuracy of threshold estimates and to control the factors that have already been proven to reduce the quality of threshold estimation. Lack of co-operation and tenseness has led to routine sedation of pseudohypacusic mine workers during ABR testing (De Koker, 2003).

Sedation might thus be needed if pseudohypacusic patients withhold co-operation.

4.3.9 APPLICATIONS OF ASSR IN CLINICAL AUDIOLOGY

Various applications for ASSR testing have been proposed in the literature:

- probing the ongoing state of a subject during operations (Sininger & Cone-Wesson, 1994);
- neonatal screening (Rickards *et al*., 1994);
- neuro-otological diagnosis of retro-cochlear abnormalities (Sininger & Cone-Wesson, 1994);
- as an electrophysiological technique analogous to speech discrimination tests (Picton *et al.* (1987) state that the ability to discriminate changes in a sound's frequency and intensity is essential to auditory perception, and Dimitrijevic *et al.* (2001) have followed the same line of thought in proposing ASSRs as an objective test for supra-threshold hearing); and
- estimating pure-tone behavioural thresholds (clearly the most important clinical application for ASSRs , particularly in difficult-to-test patients).

Pseudohypacusic patients certainly fall into the difficult-to-test category, and discussions of AEP and ASSR testing in the last two chapters raises the question whether **ASSR testing is an accurate, feasible and time-efficient way to evaluate pseudohypacusic mine workers with noise-induced hearing loss, or, more to the point, whether ASSR-based threshold estimates for this group (who are difficult-to-test and have true sensory-neural hearing loss) are accurate enough to finalise compensation and fitness-for-work assessments.**

4.3.10 APPARATUS

MF-ASSR methods use the same recording montage as ABR tests. Rance *et al.* (1995) advise the use of silver-silver chloride disk electrodes on the forehead and earlobe/mastoid, with a third electrode on the contra-lateral mastoid or cheek to serve as an earth. ASSR test systems and software require a personal computer running Windows, as well as an electroencephalogram amplifier. Earphones are inserted in addition to the electrodes.

The fact that the same electrode montage is used as for the ABR enables the clinician to perform an ABR, when needed, as well.

4.3.11 THRESHOLD DETERMINATION TECHNIQUE

Attention has been drawn to the fact that different threshold-seeking procedures may account for differences between ASSR and behavioural thresholds, where 10 dB steps have mainly been used in AEP procedures and 5 dB steps in behavioural testing.

A concern in experimental work is the lengthy procedure involved for all AEPs. Is it practicable to test at 5 dB intervals when using ASSR-methods when a clinician has a large case load as is typical in the mining industry?

4.3.12 RESPONSE GENERATORS

There has been very little research on neural generators of ASSR as a function of the modulation rate (Sininger & Cone-Wesson, 1994). The physiological interpretation of scalp-recorded ASSR latencies remains difficult. The main problem is that responses may be derived from more than one generator in the auditory pathway (John & Picton, 2000). Sininger and Cone-Wesson (1994) cite studies of ASSR neural generators in relation to modulation rate, which found that the VIII cranial nerve, cochlear nucleus, inferior colliculus and primary auditory cortex are all responsive to amplitude and frequency modulated signals.

The literature clearly indicates that, for the purpose of threshold estimation, the presence or absence of an ASSR is mainly determined by the integrity of the cochlea and the VIII cranial nerve (Dimitrijevic *et al.,* 2001). The cochlea is the area of concern in noise-induced hearing loss, at it is thus relevant to use this technique on a population with noise-induced hearing loss.

4.3.13 FREQUENCY-SPECIFICITY

As for the clinical determination of hearing thresholds, AEP threshold estimates should be provided for each ear at frequencies corresponding with the range of human speech communication (Sininger & Cone-Wesson, 1994). The reason for this is that once a person develops a hearing loss, a clinician needs to characterise its degree, type and configuration. Relevant frequency-specific information enables a clinician to apply appropriate amplification and, in the mining sector, to evaluate compensability and fitness for work. In South Africa, compensation assessments must consider hearing at 500, 1 000, 2 000, 3 000 and 4 000 Hz (Workmen's Compensation Commissioner, 1995). According to ERA Systems Pty Ltd (2000) and John and Picton (2000), ASSRs can be elicited in the frequency range between 250 and 8 000 Hz, thereby meeting the need for specificity across the range of frequencies for conventional audiometry and satisfying legal requirements.

The excellent frequency specificity of ASSRs is based on the frequency content of an amplitude-modulated stimulus that is concentrated where there is no spectral splatter (Lins *et al*., *1996).* Rance *et al.* (1995) and Lins *et al*. (1996) have shown that the configuration of hearing loss does not influence the accuracy of ASSR results.

4.3.14 RESISTANCE TO STATE OF CONSCIOUSNESS

A clinician must be aware of factors like the patient's state of consciousness, which can affect the quality of AEP measurements. ABR testing has proven to be effective, particularly for infants, since it is not affected by the infant's

state of consciousness or sleep, in contrast to the 40 Hz responses, which are considerably affected by sleep and sedation (Cohen *et al.,* 1991).

It is of the utmost importance that the testing procedures used for difficult-to-test patients are not affected by sleep or sedation, as such cases are characterised by a lack of co-operation. Testing under sedation often becomes a necessity. Cohen *et al.* (1991) and Rance *et al.* (1995) have found that ASSR techniques give reliable results for sleeping adults and children, while Hood (1998) also concludes that ASSRs evoked by tones with a modulation rate of 75 to 110 Hz are not significantly affected by sleep or sedation.

4.3.15 ABSENCE OF GENDER BIAS

During ASSR research, no evidence of gender bias has been found (Stapells *et al.,* 1984). This is not only an important clinical characteristic of a specific research technique, but it is also of specific importance in the present study, since mine workers are traditionally male and thus it is highly unlikely that a comparison between male and females in this population would be possible. Results of research using male mine workers can therefore quite possible be generalised to females as well.

4.3.16 ACCURACY OF THRESHOLD ESTIMATES

The main problem clinicians have with pseudohypacusic patients is great difficulty in obtaining the accurate, reliable and objective hearing thresholds which are imperative to meaningful assessments. This problem can possibly be overcome by using ASSRs, but clinicians must take into account that ASSR thresholds are not hearing thresholds *per se*, but physiological thresholds used to predict auditory thresholds (Sininger & Cone-Wesson, 1994).

Furthermore, it is important to acknowledge that, when one compares pure-tone and physiological thresholds, pure-tone thresholds are *influenced* by factors such as:

- instructions given to patients;
- the size of the dB step or increment used in tests;
- the earphone fit;
- background noise in the test environment; or
- the threshold determination criterion used by the audiologist, for example, a 50 per cent or a 75 per cent detection rate (Sininger & Cone-Wesson, 1994).

The above issues are not relevant to ASSRs. Electrophysiological thresholds, by contrast, are detected when they are distinct from random neural and muscle potentials, and from random airborne activity. Any factors that influence the amplitude of the response or the amplitude of the noise affect detection. Nevertheless, several researchers have found a high correlation between ASSR and pure-tone thresholds.

Lins *et al.* (1996) have found ASSR thresholds to be approximately 10 dB higher than conventional pure-tone hearing thresholds among adults with normal hearing. They have also found that threshold estimation in a group of infants was slightly worse than reported by Rickards *et al.* (1994), who found differences of 41, 24 and 35 dB hearing level at frequencies of 500, 1 500 Hz and 4 000 Hz respectively, among well babies. Lins *et al.* (1996) have tested adolescents with quantified hearing losses, and have found that ASSR measures provide reliable frequency specific information for this population.

Due to the excellent correlation found between behavioural and ASSR thresholds (an overall coefficient of 0,97 for all the frequencies tested) (Rance *et al., 1995),* a linear regression analysis has been developed to translate electrophysiological thresholds into a conventional audiogram. Use of the

regression line enables predictions of behavioural thresholds across a range of carrier frequencies to within 10 dB in 96 per cent of cases.

The accuracy of the estimation of behavioural thresholds by ASSRs is the one very important factor that will decide whether this technique will be acceptable in medico-legal investigations in general and in the mining industry in particular.

4.3.17 DETECTION OF THRESHOLDS THROUGH THE SEVERITY RANGE

The validity of ASSR thresholds in normal hearing populations has so far been the most extensively researched. Rickards *et al.* (1994), Swanepoel (2001) Schmulian (2002), Rance *et al.* (1995) and Lins *et al.* (1996) have studied the threshold estimation accuracy of ASSRs in normal hearing people, and they all conclude that ASSR is a suitable procedure for this application.

Although it has not been as extensively studied (Schmulian, 2002), threshold estimation in people with hearing loss, has also shown ASSR testing to be a suitable substitute for pure-tone testing. Lins *et al.* (1996) found the prediction of pure-tone thresholds from ASSR thresholds to be in the order of r = 82, with differences averaging between 9 and 14 dB. Rance *et al*. (1998) have tested infants and children who were candidates for cochlear implants to assess the ASSRs ability to predict severe hearing loss and establish the presence of residual hearing. ASSR thresholds were within 20 dB of pure-tone thresholds for 99 per cent of these cases, and within 10 dB for 82 per cent of them.

It can therefore be concluded that ASSR methods of threshold estimation are suited for normal and impaired hearing cases, but that estimates of hearing thresholds are better in pathological ears, due to the effects of recruitment (Rance *et al.,* 1995). This again motivates the drive to test this method in a mine worker population that is known to have a high incidence of hearing loss.

4.3.18 LACK OF AGE-RELATED INFLUENCES

The use of ASSRs has been studied for a wide range of age groups, including neonates, children, adolescents and adults. In all these groups, it has been found that ASSR testing provides a reliable and objective measure of hearing thresholds. Stapells *et al.* (1984), Sininger & Cone-Wesson (1994) and Rance *et al.* (1995) have found no age effects during ASSR testing.

It has also been proven that ASSRs are appropriate for screening neonates during the first four days after birth (Rickards *et al.,* 1994). Savio *et al.* (2001) have shown that ASSR techniques are valid, but they are the only researchers who have demonstrated changes in threshold amplitude and detectability during the first year of life. They have found that thresholds at 4 000 Hz decrease by 14 dB between birth and 12 months of age, and that such changes occurred more slowly for ASSR thresholds at lower frequencies.

Age effects are not relevant to this study, since the difficult-to-test population are all adults.

4.3.19 THRESHOLD DETECTION IN THE FREQUENCY DOMAIN

As stated previously, a critical requirement that has to be met by AEP testing is an objective detection of responses. Although no voluntary responses are needed from the patient (Lins *et al*., 1995), it is preferable that clinicians also play no role in determining or assessing the presence of a response.

When an ASSR stimulus is presented at or above a threshold, hair cells in the cochlea are activated in a locus corresponding with the carrier frequency. An analysis of the response in the cochlea and subsequent parts of the auditory pathway requires no visual detection of wave forms, nor any measurement of peak latency or amplitude. ASSRs are detected by applying computer algorithms to the recorded elctroencephologram. The algorithms analyse the magnitude and phase of the electrical activity corresponding with the modulation frequency. Lins and Picton (1995) explain that the complex wave

forms in the time-domain are transformed to the frequency-domain by means of Fast-Fourier processing. In the frequency-domain, the analysis is done using spectral analysis techniques.

ERA Systems Pty Ltd (2000), the manufacturers of the Audera ASSR system, state that 64 samples are analysed in each trial, which comprises a tone of a specific frequency-amplitude combination, for example, 1000 Hz at a 30 dB hearing level. In each electroencephalogram sample, the magnitude and phase of the electrical activity corresponding with the modulation frequency are quantified and shown as a vector in a polar plot. The vector's length represents amplitude, and its angle reflects the phase or time delay between tone modulation and the brain's response (ERA Systems Pty Ltd, 2000).

When vectors are clustered, this indicates a phase-locked brain response; in other words, the electroencephalogram samples are synchronised with the tone modulation frequency, which can only occur if the ear and brain have responded to a sound. Vectors distributed randomly around the polar plot indicate a lack of phase relationship between the electroencephologram and tone modulation (no response).

Statistical analyses are done in real-time as samples are collected, and the analysis algorithms (Sininger & Cone-Wesson, 1994) halt stimulation and data sampling when certain probability values have been obtained, for example, p (probability value)<0, 3.

The statistical analysis of vector phases uses a measure known as phase coherence squared (PC^2), calculated as each new vector is obtained for an electroencephalogram sample. The resulting PC^2 values can range from 0 to 1, with values approaching 0 indicating low phase coherence between the sample and tone, and those approaching 1 indicating high phase coherence.

The PC^2 value is evaluated using statistical tables of circular variance to obtain a probability value, "p". This level of significance is thus determined by

a statistical test and gives an indication of whether a response is present. A probability value of p<0,03 sets the false positive rate for ASSR detection at 3 per cent (there is a less than 3 per cent chance that results are due to noise alone). A trial contaminated by excessive noise is automatically terminated, labelled as such and excluded from further evaluations. The lowest level at which a phase-locked response is obtained is taken as the electrophysiological threshold, which is used to estimate pure-tone behavioural thresholds by means of an algorithm based on the research of Rance *et al*. (1995) (see Figures 5.14 to 5.18).

Picton *et al.* (2001) has found that detection protocols based on both phase and amplitude (the f-test and the phase-weighted t-test) are more effective than those using phase alone (phase coherence and phase-weighted coherence) (Stapells *et al*., 1984; Aoyagi *et al.,* 1994). The f-test evaluates whether a response to the stimulus differs from noise in the recording at adjacent frequencies (Lins *et al.*, 1996; Perez-Abalo *et al*., 2001), and the T2 statistic determines whether a response is replicable across a number of averaged responses (Valdez *et al.,* 1997; Picton *et al.,* 1987). Lins *et al.,* (1996) have found the f-test to be slightly more effective than the T2 test. Picton *et al.* (2001) have found that using both the phase and the amplitude data in detection protocols identified more ASSRs than phase data alone.

The above detection of responses and thus threshold estimation objectively done by means of computer algorithms is the most important reason for evaluating this technique in an adult population with pseudohypacusis, since this objectivity has been lacking in traditional AEP testing.

4.3.20 ASSESSMENT OF SOUND PROCESSING

ASSR testing has created the possibility of evaluating sound processing by means of binaural stimulation, rather than traditional monaural stimulation. Multi-sensory processing and interactions between the visual and auditory systems have not yet been researched (Schmulian, 2002), but a possibility

may exist that one could use ASSRs in the evaluation of reading difficulties where auditory and visual processing abnormalities coincide. The possible advantages of evaluating a patient's hearing using this technique would be the fact that binaural multiple-frequency stimulation can approximate human hearing to a much greater degree than monaural pure-tone testing does.

4.4 SUMMARY

In this chapter, auditory steady state responses have been defined and put into a historical perspective. The relevant testing parameters have been discussed with reference to their importance for a pseudohypacusic adult population. Advantages and disadvantages of this AEP have been evaluated in order to decide on the possibility of using this method as a threshold estimation technique in adults with noise-induced hearing loss.

A summary of the current research findings related to the rationale for the clinical and research use of ASSRs is set out in Table 4.1 below.

TABLE 4.1: RATIONALE FOR THE SELECTION OF ASSR IN EXPERIMENTAL RESEARCH WITH MINE WORKERS

ADVANTAGE OF ASSRs	REFERENCES
Objective threshold estimation	Sininger and Cone-Wesson (1994) ERA Systems Pty Ltd (2000) Rance *et al. (1995)*
Frequency-specificity	Sininger and Cone-Wesson (1994) ERA Systems Pty Ltd (2000) John and Picton (2000) Lins *et al*. (1996) Rance *et al*. (1995)
Resistance to state of consciousness	Cohen *et al*. (1991) Rance *et al. (*1995) Hood (1998)
Absence of gender bias	Stapells *et al.* (1984)
No amplitude deterioration with pathology	Schmulian (2002)
Correlation with behavioural thresholds	Sininger and Cone-Wesson (1994) Lins *et al*. (1994) Rance *et al.* (1995)
Response generators: cochlea and VIII nerve	Dimitrijevic *et al*. (2001)
Application in threshold estimation	Rance *et al.* (1995) Rickards *et al.* (1994)
Age unimportant	Stapells *et al*. (1984) Rance *et al*. (1995) Rickards *et al*. (1994)
Tonal stimuli	Rob *et al*. (2000) Rance *et al*. (1995)
Stimulation of eight simultaneous frequencies	Perez-Abalo *et al*. (2001) Herdman and Stapells (2001)
Accurate throughout severity range	Rickards *et al*. (1994) Rance *et al*. (1995) Lins *et al*. (1996) Rance *et al*. (1998)

The above theoretical advantages indicated in Table 4.1 motivated the application of ASSRs in an empirical clinical study as is discussed in Chapter 5.

CHAPTER 5

RESEARCH METHODS

AIM

This chapter's aim is to describe and justify the methodology followed in the empirical research of the study. The end goal is to answer the research question: What is the clinical value of ASSRs in the audiological evaluation of pseudohypacusic mine workers with noise-induced hearing loss?

5.1 INTRODUCTION

The research question put forward in Chapter 1 centres around the clinical value of auditory steady state response methods in audiological assessments of pseudohypacusic mine workers with noise-induced hearing loss.

In the South African mining industry a large number of workers (between 68 and 80 per cent) are exposed at equivalent levels of noise exceeding 85 dB (Franz & Phillips, 2001). The high incidence of noise-induced hearing loss, combined with workers' awareness of noise-induced hearing loss compensation, creates a situation in which workers commonly exaggerate symptoms of their hearing loss for compensation purposes. Conventional assessment methods available to audiologists currently fail to provide accurate and reliable hearing thresholds in such cases, delaying the conclusion of some claims and, in all likelihood, resulting in overcompensation of others.

Promising alternative methods to address the current situation include auditory tests utilizing evoked potentials (AEPs: Chapter 3) and more specifically auditory steady state response testing (ASSRs: Chapter 4). The need to be met is for a once-off test, capable of concluding diagnostic procedures, for pseudohypacusic

workers by estimating accurate hearing thresholds for compensation claims and "fitness-for-duty" assessments. According to most of the literature reviewed, ASSR testing provides an accurate means of predicting pure-tone hearing thresholds without any need for the patient to respond to the sound - thus providing a possible solution to the research question.

In a survey of the literature it has become clear that primarily two modulation frequencies have been used in research with ASSRs, that is 40 Hz (Stapells *et al.,* 1984) and 80 to 110 Hz (Lins & Picton, 1995). There are also currently two stimulation methods namely monotic (Rickards *et al*., 1994) and dichotic (Perez-Abalo *et al.,* 2001). These presentation variations need to be taken into consideration when planning empirical research in this field. The fact that auditory evoked potentials are affected by the state of consciousness of the patient (Dobie & Wilson, 1998) is another important aspect to incorporate in the research design especially in situations were the co-operation or lack of co-operation of the patient is a factor that can influence the assessment outcome. It is thus clear that empirical research designed to answer the stated research question will of necessity be complex and involved.

5.2 AIMS OF THE RESEARCH

The aims of the present research are detailed in the sections below:

5.2.1 PRINCIPAL AIM

The principal aim of the study was to determine the clinical value of ASSR methods in the hearing assessment of pseudohypacusic mine workers presenting with noise-induced hearing loss.

Roeser *et al*. (2000b) drew attention to the fact that the effectiveness of an audiological test needs to be evaluated. The same authors stated that tests

could be evaluated to decide on validity, reliability, sensitivity and specificity. An audiological test's value lies in its ability to perform as intended. In order to determine the value of ASSR tests the norm for "clinical value" was the threshold estimation ability of this procedure. Could ASSR tests accurately estimate pure-tone thresholds in a pseudohypacusic population in order to conclude diagnostic procedures and thus facilitate in correct and meaningful recommendations regarding rehabilitation?

Apart from the clinical efficiency in estimating thresholds, the cost- and time efficiency of ASSR methods will also aid in decisions related to the ultimate value of the specific method.

5.2.2 SUB AIMS

The principal aim of the study, to decide on the threshold estimation ability of ASSRs in a pseudohypacusic population, can only be attempted if ASSRs have been validated in an adult mine worker population with noise-induced hearing loss. Since this procedure has not been validated in this population the sub-aims are:

5.2.2.1 To compare ASSR and pure-tone thresholds in a co-operative population of adult mine workers with sensory neural hearing loss

The clinical value of ASSR techniques, in other words the ability to estimate pure-tone thresholds, has to be investigated for co-operative noise-exposed mine workers and specifically those with identified noise-induced hearing loss. The pure-tone and ASSR threshold estimates of all the subjects need to be compared in order to evaluate the effectiveness of ASSRs in estimating pure-tone thresholds. All the frequencies specified in legislation for the mining industry should be tested, namely, 500, 1 000, 2 000, 3 000 and 4 000 Hz (RMA guidelines, 2003) and in both ears.

5.2.2.2 To compare the accuracy of multiple-frequency (dichotic) and single frequency (monotic) ASSR stimulation methods in estimating pure-tone thresholds in a mine worker population

The effectiveness of multiple-frequency (MF) ASSR and single frequency ASSR methods for threshold estimates should be compared in order to make recommendations regarding the most effective method possible. The reason being that time saving is an important factor in an industry with large case loads. The ASSR threshold estimates for both these stimulation methods are compared to pure-tone thresholds. Comparing the testing time of both stimulation methods will also be an indication of the stimulation method of choice.

5.2.2.3 To compare different modulation frequencies' effectiveness in estimating pure-tone thresholds

Modulation frequencies of 40 and 80 to 110 Hz are usually used in ASSR testing. Threshold estimates obtained when using the different modulation frequencies are compared to pure-tone thresholds. A decision regarding the most accurate and time effective modulation frequency for carrier frequencies in ASSR testing of adults with impaired hearing is then possible.

5.2.2.4 To determine the effect of sedation on the ASSR test's ability to estimate pure-tone thresholds

In order to evaluate the effect of sedation on the threshold estimates obtained with ASSR tests, the threshold estimates' accuracy with and without sedation needs to be compared. The testing time with and without sedation will aid in the above decision.

The reason why a study of the effect of sedation is needed is that the 40 Hz response will be used in the experimental phase. There are contradictory research results with regard to the effect of sedation on the 40 Hz response. The dramatic effect of sleep and state of consciousness on the 40 Hz response has

been cited by Galambos *et al*. (1981). Dobie and Wilson (1998) in comparison could find no real negative influence of sedation on the 40 Hz response of adults. See Section 4.3.14.

5.2.2.5 To determine if pure-tone threshold estimates can be obtained in unco-operative mine workers

In a clinical situation pseudohypacusic patients do not co-operate and accurate hearing thresholds cannot be obtained. ASSR methods were used in a group of unco-operative mine workers to investigate if thresholds could be obtained. ASSR thresholds were compared to pseudohypacusic pure-tone thresholds and the information gained from the ASSR thresholds were analyzed in order to obtain clinical information.

5.3 RESEARCH PLAN

The discussion below focuses on the research design as the strategic framework for action that serves as a bridge between the research question and the execution of the research (Dane, 1990).

An empirical study was conducted. Mouton (2001) describes an empirical study as the use of primary and numerical data with high control. Sources of data used in this study were physical measurements: in this case auditory thresholds. An experimental research method was also selected for this study (Leedy, 1997). In experimental research, the researcher attempts to maintain control over all the factors that may affect the result of an experiment (Key, 1997). The strength of an experimental design lies in its ability to infer causality and test causal relationships. One limitation of an experimental design that needs to be addressed is the fact that small sample sizes make generalisability risky (Mouton, 2001).

The research was also quantitative. Berg (1998) explains that quantitative research has to provide rigorous, reliable and verifiably large aggregates of data,

and that quantitative research can be regarded as a formal and systematic process. In this study, the experimental research process was pursued by using a quasi-experimental design, as described by De Vos (2002). The main disadvantage of this method is the lack of a control group – the difficulty with including a control group in this study or doing different ASSR procedures on the same group was the lengthiness of these procedures. To prevent bias from creeping in, it was therefore important to ensure a random allocation of subjects to different sub-groups.

In order to answer the research question and to meet the research aims set out in Section 5.2 (the clinical value of ASSR testing in a population of pseudohypacusic mine workers with noise-induced hearing loss), a multi-group design was followed (De Vos, 2002): six experimental groups were organised and utilised in two research phases. Groups 1,1 to 1,5 were mine workers (co-operative) with proven noise-induced hearing loss and Group 2 were non-co-operative mine workers with suspected pseudohypacusis. The research plan is logically set out in Table 5.1.

TABLE 5.1: RESEARCH PLAN: PHASES, EXPERIMENTAL GROUPS AND EXPERIMENTAL PARAMETERS

Research phase	Experimental groups	Instrument	Modulation frequency (Hz)	Monotic/dichotic Stimulation	Sedation	Number of subjects	Type of hearing loss
Phase 1	1,1	Audera	80-110	Monotic	No	12 (subject 1-12)	NIHL
	1,2	Audera	40	Monotic	No	16 (subject 13-28)	NIHL
	1,3	MASTER Biologic	80-110	Dichotic	No	20 (subject 29-48)	NIHL
	1,4	Audera	40	Monotic	Yes	13 (subject 49-61)	NIHL
	1,5	MASTER Biologic	80-110	Dichotic	Yes	20 (subject 62-81)	NIHL
Phase 2	2	Audera	40	Monotic	No	29 (subject 82-119)	Pseudohy-pacusis

Different ASSR test procedures were used on the different groups in order to compare the different methods' ability to estimate pure-tone thresholds.

The selection and grouping of the 81 subjects for Phase 1 (co-operative subjects with noise-induced hearing loss) in the different groups listed (Table 5.1) enabled the following comparisons:

- All 81 subjects' pure-tone and ASSR thresholds (Groups 1.1, 1.2, 1.3, 1.4 and 1.5) could be compared to decide whether ASSR thresholds can estimate pure-tone thresholds accurately.
- ASSR-thresholds' accuracy, obtained with an 80 to 110 Hz stimulation rate (1.1, 1.3 and 1.5) (Rickards & Clark, 1984) could be compared to the

ASSR thresholds' accuracy obtained using a 40 Hz stimulation rate (Groups 1.2 and 1.4) (Rance *et al.*, 1995).

- A comparison of the prediction value of ASSR thresholds was possible when multiple frequency and single frequency ASSR procedures were followed (Groups 1.1, 1.2, 1.4 vs 1.3 and 1.5) (Perez-Abalo *et al.*, 2001 and Rance *et al.*, 1995).
- Lastly, a comparison between the ASSR and pure-tone thresholds was possible between sedated and non-sedated subjects (Groups 1.1, 1.2 and 1.3 *versus* Groups 1.4 and 1.5).

The testing of subjects in Phase 1 was used to determine the most effective test equipment, stimulation rate and stimulation method (multiple- or single frequency), as well as the effect of sedation, thereby establishing a protocol of choice for a population with noise-induced hearing loss.

- The last experimental group was a group of mine workers (29) with known noise-exposure but who were not co-operating and for whom thus no pure-tone thresholds were available (Phase 2). The goal was to determine whether ASSR thresholds can be obtained for unco-operative subjects. The questions to be answered were whether thresholds can be obtained at all the needed frequencies for unco-operative patients and in what space of time this can be done.

A total of 110 subjects participated in the study.

5.4 ETHICAL CONSIDERATIONS

Ethical concerns need to be taken into account in order for research to be conducted in a manner which is fair to all the participants and employers. Furthermore research ethics, according to Neuman (1997), define what is legitimate and moral during research. For the purposes of this study, the

following ethical aspects were taken into account: willing participation, informed consent, permission for the use of sedation, employers' permission and ethical clearance. These aspects are discussed in more detail below.

5.4.1 WILLING PARTICIPATION

Subjects were assured that if they chose not to participate in the study, they would not be disadvantaged in any way. Workers who did not wish to participate were routed back for a continuation of standard medical surveillance procedures. Subjects were not coerced or manipulated into volunteering, in line with the principles set out by Berg (1998). Subjects were also able to withdraw from the research whenever they chose to do so, in accordance with the ideas of Strydom (1998).

5.4.2 INFORMED CONSENT

Informed consent was obtained in writing from each subject (see Appendix A for the form used). Obtaining such consent implies that the worker was informed about the goal of the investigation and the procedures followed. The presentation of accurate and complete information was emphasised, so that subjects fully comprehended the investigation, in accordance with suggestions by De Vos (2002). The subjects' comprehension of the procedure was aided by providing a trained African languages translator. Voluntary participation was the goal and subjects were assured of anonymous participation.

5.4.3 CONSENT TO SEDATION

Apart from the informed consent obtained as stated in Section 5.4.2 (above), subjects who would be sedated were supplied with a patient information sheet on the effect of the medication (see Appendix B). Additional consent (see Appendix B) for this participation was also obtained in writing with the help of a translator. The subjects who gave consent were then referred to an Ear-, Nose- and Throat

specialist or occupational medical practitioner (OMP) who perused the subjects' medical history and prescribed the sedation. The sedation of the subjects took place at Occupational Health Centres (OHCs) where an OMP was on duty. After their participation, the subjects were transported back to their hostels. They only returned to work the following day.

5.4.4 EMPLOYERS' PERMISSION

Permission to involve their employees was obtained from the mining companies whose workers participated (Gold Fields - see Appendix C, and Harmony - see Appendix D).

5.4.5 ETHICAL CLEARANCE

Ethical clearance was obtained from the University of Pretoria's Ethics Committee (Faculty of Humanities) and the Research Committee of the Department of Communication Pathology (see Appendix E).

5.5 SUBJECTS

5.5.1 POPULATION

The population of this study, in other words, all the individuals who possessed the specific characteristics that represent the measurements of interest in the study as described by De Vos (2002) were South African mine workers with noise-induced hearing loss (Phase 1) and pseudohypacusic South African mine workers (Phase 2). A population of mine workers was selected from workers undergoing their annual Certificate of Fitness assessments at their mines' Occupational Health Centres in the Randfontein and Carletonville areas. All the subjects worked underground and, hence, had been exposed to hazardous noise (Franz & Phillips, 2001).

5.5.2 SAMPLING

Results from a study can only be generalised if the sample tested is seen to be representative of the population. A sample is, in other words, a small portion of the total set of persons that comprise the subject of the study (De Vos, 2002). The reason for sampling is feasibility, since it is impossible to include all the possible members of a population of this nature.

Non-probability quota sampling (Neuman, 1997; De Vos, 2002) was used in this study, in other words, in the selection of an underground mine worker in the predetermined group. Any subjects who happened to undergo medical surveillance at the OHC and who had noise-induced hearing loss and worked underground were included in the sample. All potential subjects complying with the selection criteria were selected, within the time constraints imposed by the length of a working day and the lengthy test procedures. A three-month period was allowed for the experimental research, from September to November 2002.

The objective was to conduct experimental testing on the same day as medical surveillance procedures, to prevent interference with normal production at the mines. It was not always possible to achieve this, particularly with subjects who had been sedated, since the occupational medical practitioner had to peruse the worker's medical history and prescribe the sedation.

A total of 81 male subjects (162 ears) between the ages of 23 and 60 were selected for the first phase of the research and 29 (58 ears) were selected for the pseudohypacusic group. The sample size was verified by a statistician of the Medical Research Council (Pretoria).

5.5.3 CHARACTERISTICS OF SUBJECTS AND THE PROCEDURES FOLLOWED IN THE SELECTION OF THESE SUBJECTS

5.5.3.1 Occupation

Subjects had to be mine workers (in a gold mine) allocated to underground duties and therefore exposed to hazardous noise. Noise exposure was important since the study aimed to evaluate the effectiveness of ASSR techniques in subjects with noise-induced hearing loss. Occupational Health Centre staff verified that these workers did indeed work underground.

5.5.3.2 Abnormal hearing with and without a functional overlay

As mentioned previously, the population under scrutiny was one of mine workers with proven noise-induced hearing loss. The subjects had to have sensory neural hearing loss (no persons with mixed and conductive hearing losses were selected) and proven noise exposure of more than five years (Begley, 2003). In order to confirm exposure to hazardous noise and exclude other possible causes of sensory-neural hearing loss (for example, ototoxic drugs, ear infection and head injury), a case history (see Appendix G) was compiled and recorded by a trained African languages translator.

Based on the aims of the study, it is clear that the subjects in the study had to have hearing loss. Subjects (without a functional overlay) were required to have a pure-tone average exceeding 25 dB (500, 1 000, 2 000, 3 000 Hz) thereby qualifying them for consideration for noise-induced hearing loss compensation. This criterion was derived from the legislation implemented in the South African mining industry at the time when the experimental research was done, namely the Workmen's Compensation Commissioner's (WCC) internal instruction 168, 1995. Hearing loss is also commonly defined in the literature as hearing thresholds worse than 25 dB (Northern & Downs, 1991). The initial selection was done on the basis of the results of the screening hearing test done during medical surveillance. Pure-tone air- and bone conduction audiograms performed

by audiologists in a controlled environment on the same subjects served as a confirmation of the screening thresholds.

A group of pseudohypacusic workers (functional overlay) was also evaluated. By definition their true hearing status was unknown since they exaggerate their true hearing thresholds (Martin, 2000). Two pure-tone audiograms were performed at 500, 1 000, 2 000, 3 000 and 4 000 Hz, to enable threshold comparisons for the purpose of identifying pseudohypacusis. A difference of 15 dB or more (Rintelmann *et al.*, 1991) at all the frequencies and in both ears was regarded as an indication of pseudohypacusis. The two audiograms recorded used different threshold determining techniques, namely the ascending (first procedure) and descending methods (Rintelmann *et al.,* 1991). The two audiograms were performed by the same audiologist in the same environment during two consecutive test sessions. This group of workers also had to have normal middle ear function to exclude conductive hearing loss and proven noise exposure to fit into the category of mine workers with sensory neural hearing loss.

5.5.3.3 Normal middle ear function

Normal middle ear function was a prerequisite for subject selection. The findings of Hood (1995) and Hall and Mueller (1997) have indicated that middle ear pathology affects ASSR amplitude. To exclude cases of middle ear pathology and conductive impairment, subjects had to have normal middle ear function. Furthermore, normal middle ear function was also included as a criterion since a population of people with noise-induced hearing loss was the focus of the study.

Middle ear function was assessed by means of tympanometry. The following selection criteria (indicating normal middle ear functioning) were applied to the tympanometry results:

- ear canal volume: 0,5-1,5 cc;
- compliance: 0,3-1,6 cc (Stach, 1998);
- Type A tympanograms – Northern and Downs (1991) define Type A tympanograms as adequate compliance and normal middle ear pressure at the point of maximal compliance. Normal middle ear pressure was taken as –50 mm to +50 mm H2O.

Normal middle ear function was further verified by otoscopy. Otoscopic examinations were performed on both ears for each subject, to identify any middle ear/tympanic membrane pathology or obstruction of the external auditory meatus that could affect the conduction of sound, as proposed by Stach (1998).

Finally, an air-bone gap of 10 dB indicating possible middle ear abnormalities excluded some subjects (Roeser *et al*., 2000b).

5.5.3.4 Age and gender

All the subjects were male. This was not a prerequisite of the study but arose from the fact that the vast majority of mine workers in South Africa are traditionally male. Stapells *et al.* (1984) have proven that there is an absence of gender bias with ASSR testing and thus the results will be applicable to both sexes. Because Hood (1998) has shown that electrophysiological tests show no age effects between 10 and 60 years, it was required that the age of all subjects be within this range. This requirement was easily met, since the working age of mine workers is between 18 and 60 years. The age information was obtained from patient files and the case history information (see Appendix G).

5.5.4 DESCRIPTION OF SUBJECTS

The subjects who eventually participated in this study and their characteristics are described in the following tables and figures.

5.5.4.1 Hearing thresholds - co-operative group

Table 5.2 supplies hearing thresholds in decibels at all the frequencies required for the subjects with noise-induced hearing loss without a functional overlay.

TABLE 5.2: HEARING THRESHOLDS (DECIBEL)(HL) FOR THE CO-OPERATIVE GROUP

PURE-TONE THRESHOLDS FOR LEFT EAR					PURE-TONE THRESHOLDS FOR RIGHT EAR					
500Hz	1000Hz	2000Hz	3000Hz	4000Hz	500Hz	1000Hz	2000Hz	3000Hz	4000Hz	Subject
60	80	60	55	65	40	70	60	55	70	1
20	45	55	50	50	20	45	40	40	45	2
35	45	50	35	30	30	40	40	35	30	3
10	50	55	55	60	10	45	50	60	50	4
15	25	45	55	65	20	20	25	50	60	5
5	5	40	65	80	5	10	35	70	70	6
15	40	50	75	75	25	30	30	50	55	7
15	25	30	35	35	15	30	35	30	30	8
30	45	45	50	50	25	40	40	45	50	9
20	20	20	30	35	15	25	20	30	30	10
30	45	35	40	45	30	40	45	35	45	11
35	40	35	35	40	30	30	20	40	45	12
10	15	50	55	55	10	15	50	65	50	13
40	45	40	70	75	30	45	35	45	55	14
20	45	70	80	70	10	35	60	60	55	15
25	35	45	50	50	20	40	45	50	55	16
15	35	40	45	40	5	25	40	45	45	17
25	40	35	30	40	25	40	25	35	35	18
10	30	45	35	35	5	35	45	35	35	19
15	35	45	45	40	10	20	35	40	40	20
15	45	35	25	40	20	50	55	55	50	21
40	50	55	65	70	25	50	50	60	65	22

PURE-TONE THRESHOLDS FOR LEFT EAR					PURE-TONE THRESHOLDS FOR RIGHT EAR					
500Hz	1000Hz	2000Hz	3000Hz	4000Hz	500Hz	1000Hz	2000Hz	3000Hz	4000Hz	Subject
10	30	45	50	50	30	25	40	45	65	23
50	50	40	15	25	50	50	40	20	15	24
20	25	45	35	40	5	15	25	25	30	25
30	45	50	55	55	30	50	50	60	60	26
20	35	35	40	45	20	35	45	40	45	27
35	40	35	35	40	30	30	20	40	45	28
45	55	55	50	50	35	60	55	55	60	29
10	30	40	50	40	15	15	35	45	30	30
40	40	35	25	25	45	55	50	50	50	31
20	30	35	35	25	15	30	40	20	25	32
10	30	50	55	65	10	20	50	50	65	33
5	15	50	45	45	5	20	35	40	55	34
30	40	35	30	25	30	25	35	30	40	35
10	45	60	45	50	5	45	60	55	60	36
15	25	55	60	80	5	5	35	50	80	37
30	40	60	65	65	20	25	30	45	55	38
20	25	30	55	65	15	25	35	60	90	39
30	40	50	50	55	25	30	50	50	50	40
30	45	40	50	35	30	35	30	30	45	41
15	25	45	45	50	20	30	45	55	55	42
15	20	50	45	45	10	25	30	60	65	43
45	65	65	70	75	45	55	55	65	75	44
0	30	50	60	55	0	20	30	65	50	45
10	45	45	50	50	10	35	45	55	40	46
25	20	35	55	60	20	50	50	45	55	47
30	45	40	50	40	30	45	40	35	35	48
5	10	30	40	45	10	15	40	40	45	49
30	55	60	60	60	35	50	50	60	65	50
15	20	35	40	40	15	30	35	45	50	51

PURE-TONE THRESHOLDS FOR LEFT EAR					PURE-TONE THRESHOLD FOR RIGHT EAR					
500Hz	1000Hz	2000Hz	3000Hz	4000Hz	500Hz	1000Hz	2000Hz	3000Hz	4000Hz	Subject
10	20	35	55	50	15	20	35	45	55	52
20	50	50	50	55	30	50	45	45	55	53
15	65	75	70	65	30	65	75	75	80	54
5	20	30	35	40	20	30	50	55	50	55
15	40	45	55	50	15	45	55	50	50	56
25	45	55	60	65	25	35	55	65	65	57
5	15	15	85	85	15	20	10	75	85	58
30	35	30	50	60	30	45	45	55	50	59
10	30	45	45	45	10	30	40	50	40	60
20	40	45	50	40	5	15	35	40	30	61
20	40	60	60	55	10	30	55	55	40	62
35	40	55	55	75	25	40	35	40	65	63
20	40	45	55	50	10	35	40	45	55	64
15	50	50	45	50	20	45	50	45	55	65
15	25	75	75	75	10	25	55	45	45	66
20	55	50	60	60	25	50	55	60	60	67
15	40	45	40	40	25	40	45	45	50	68
25	45	45	50	35	30	45	45	50	45	69
0	25	40	50	60	5	20	35	50	65	70
15	20	40	30	25	15	25	45	40	40	71
30	40	40	40	50	25	35	55	65	60	72
25	40	35	35	40	30	40	40	35	40	73
30	40	50	50	60	25	30	50	55	65	74
20	45	55	50	50	20	45	45	45	55	75
15	40	50	50	50	20	40	45	40	50	76
30	30	35	55	50	20	50	60	55	65	77
20	40	45	30	30	20	45	35	35	20	78
30	40	45	40	45	30	40	45	40	45	79
10	35	55	45	35	10	25	40	40	45	80
30	60	50	50	45	35	60	55	50	50	81

To summarise the information in the above table: it can be seen that the subjects had hearing thresholds representing different degrees of hearing loss, ranging from mild (26-40dB), moderate (41-65dB) to severe (66-95dB). The numbers of hearing thresholds per frequency in the different severity ranges were the following:

- Mild hearing thresholds – 251.
- Thresholds indicating moderate hearing loss – 346.
- Thresholds indicating severe hearing loss – 32.
- Due to the sloping nature of sensory-neural hearing loss, 181 normal thresholds (0-25dB) were also obtained, mainly in the 500 Hz area.

5.5.4.2 Age of co-operative group

The subjects were 81 male mine workers with noise-induced hearing loss between the ages of 23 and 60 years. Figures 5.1 to 5.5 represent the age distributions of mine workers with noise-induced hearing loss across five-year age intervals. The subjects were randomly assigned to different groups to study the influence of different ASSR-equipment and techniques on the comparison of the ASSR and pure-tone thresholds. The structure for this was already indicated in Table 5.1.

In addition, in Figures 5.7 to 5.12, the participants' years of noise exposure in the mining industry and their age is indicated for the different research groups and the different experimental phases.

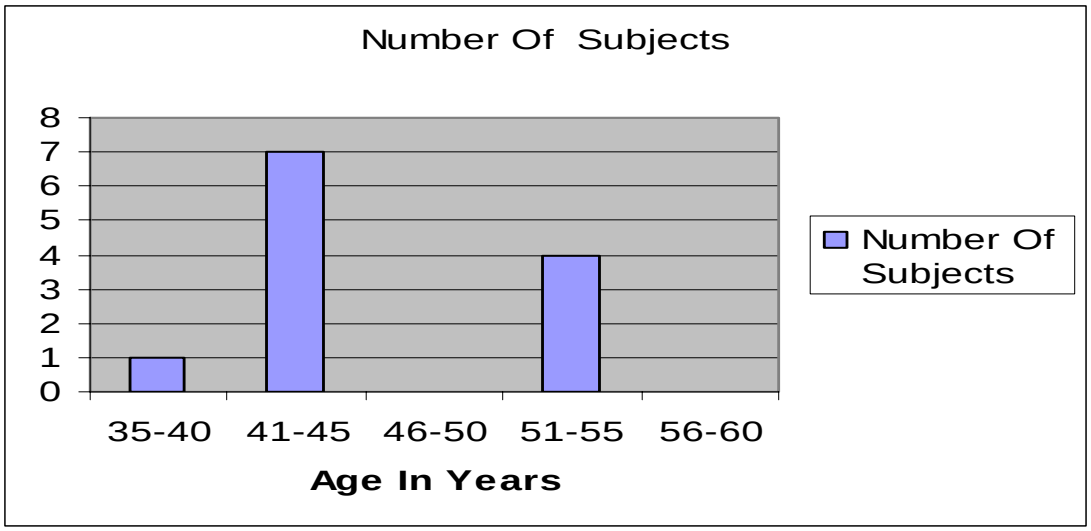

FIGURE 5.1: AGE DISTRIBUTION OF THE SF/80 HZ/NON-SEDATED GROUP (n=12): MEAN AGE 45,8 YEARS

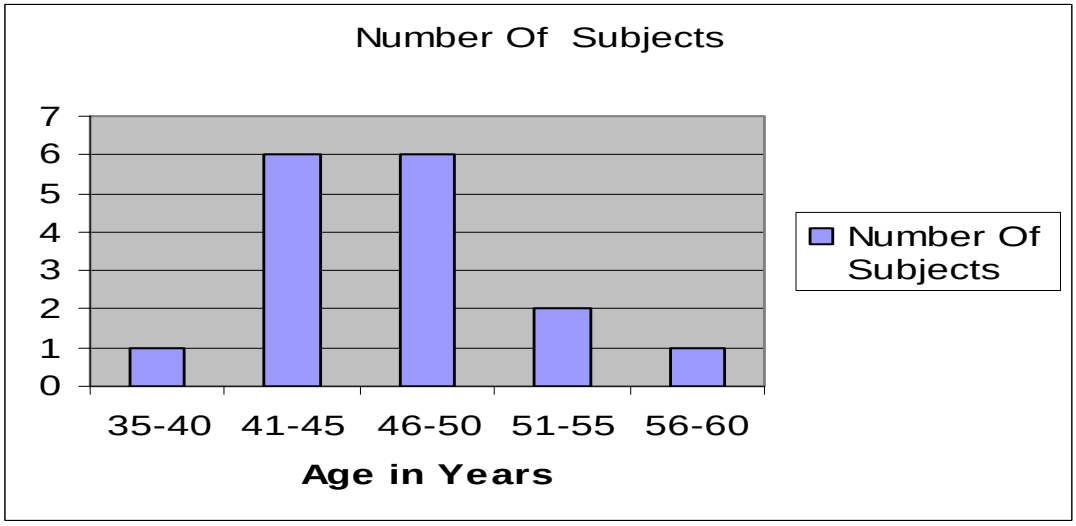

FIGURE 5.2: AGE DISTRIBUTION OF THE SF/40 HZ/NON-SEDATED GROUP (n=16): MEAN AGE 47,5 YEARS

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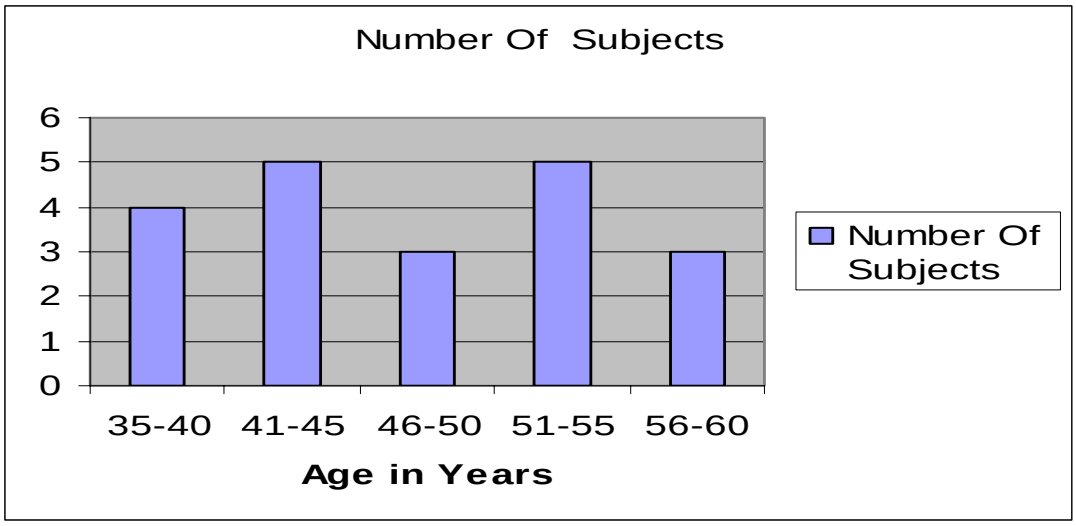

FIGURE 5.3: AGE DISTRIBUTION OF THE MF/80 HZ/NON-SEDATED GROUP (n=20): MEAN AGE 46,38 YEARS

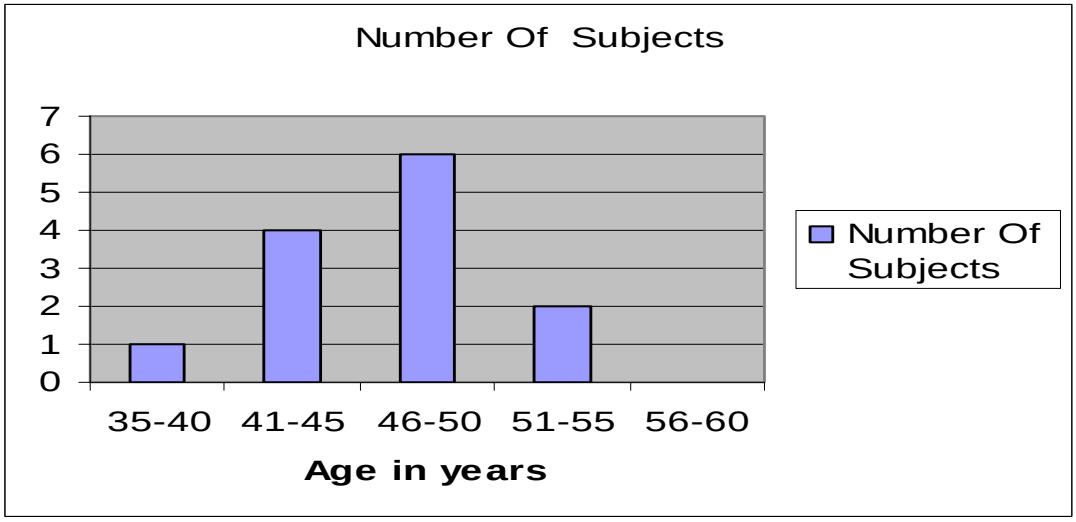

FIGURE 5.4: AGE DISTRIBUTION OF THE SF/40 HZ/SEDATED GROUP (n=13): MEAN AGE 47,3 YEARS

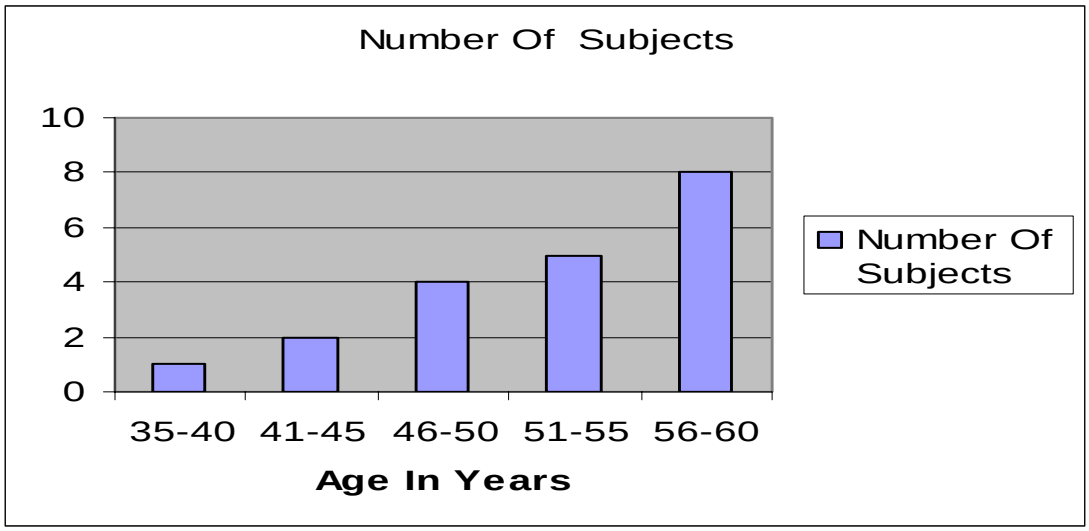

FIGURE 5.5: AGE DISTRIBUTION OF THE MF/80 HZ/SEDATED GROUP (n=20): MEAN AGE 52 YEARS

5.5.4.3 Age distribution of pseudohypacusic group

The group of mine workers with pseudohypacusis consisted of 29 subjects. In Figure 5.6, the age distribution of this group is shown.

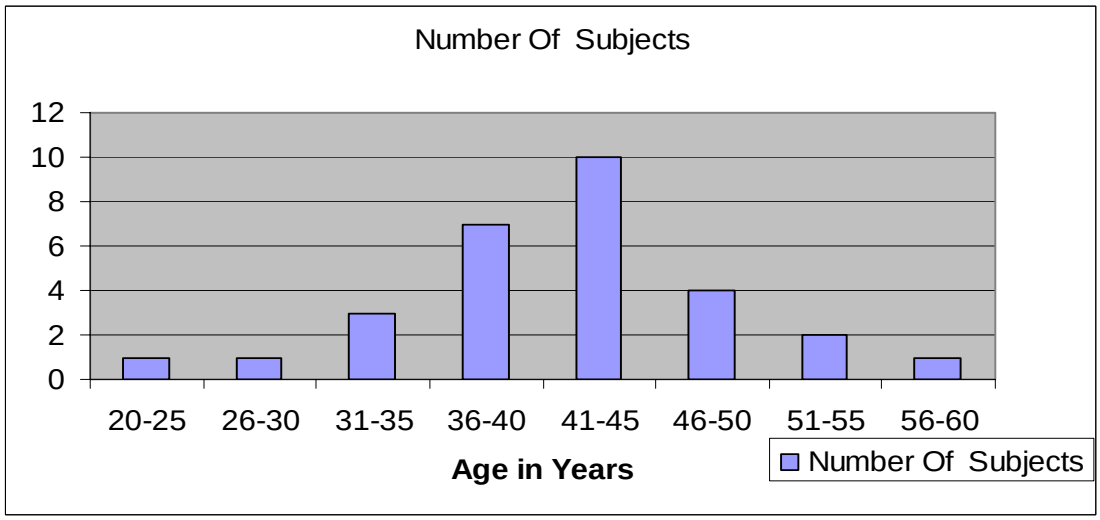

FIGURE 5.6: AGE DISTRIBUTION OF PSEUDOHYPACUSIC GROUP (n=29): MEAN AGE 41,86

5.5.4.4 Years of experience/exposure

Figures 5.7 to 5.11 represent the experience and hence period of exposure for various sub-groups within the experimental groups.

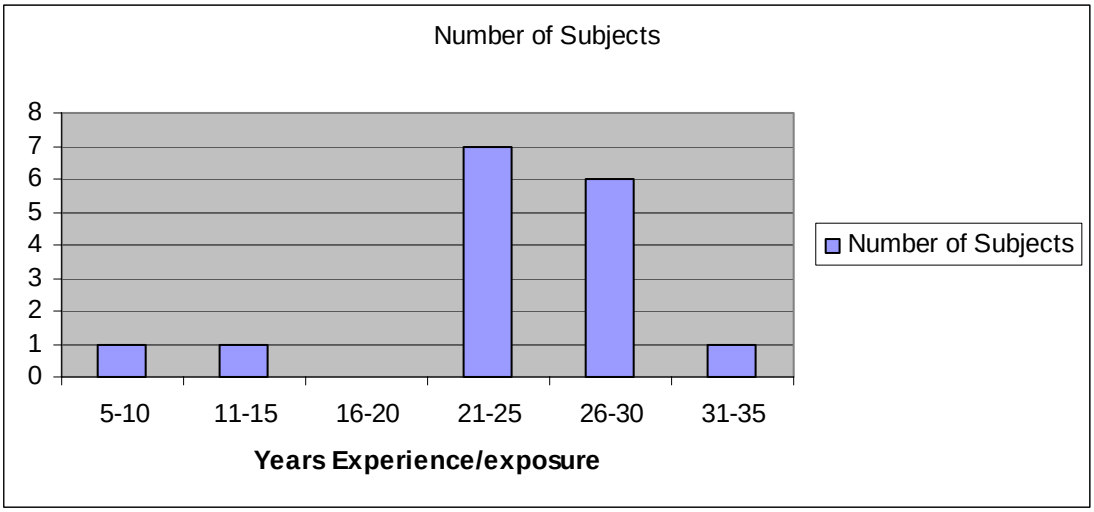

FIGURE 5.7: EXPERIENCE/EXPOSURE: SF/80 HZ/NON-SEDATED GROUP

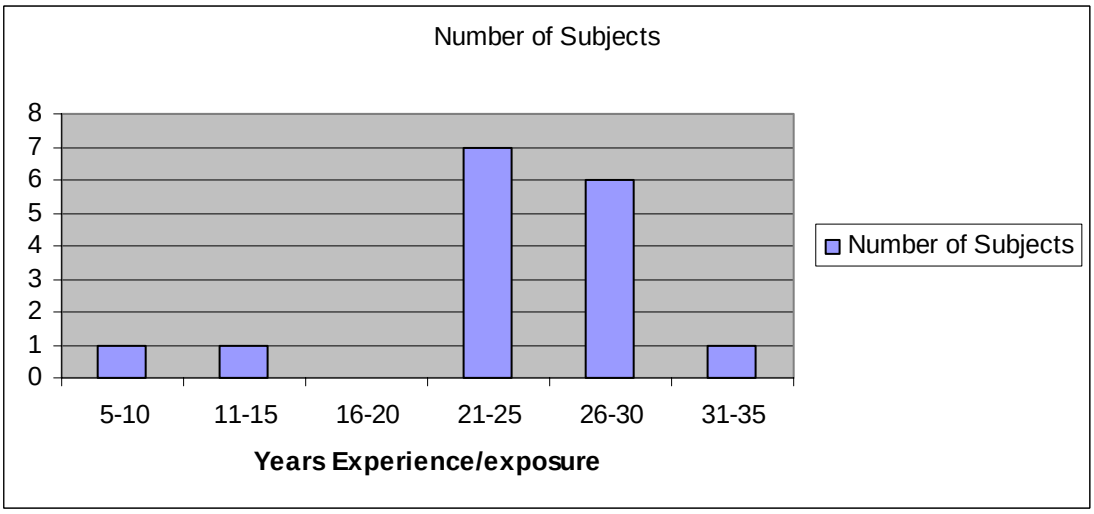

FIGURE 5.8: EXPERIENCE/EXPOSURE: SF/40 HZ/NON-SEDATED GROUP

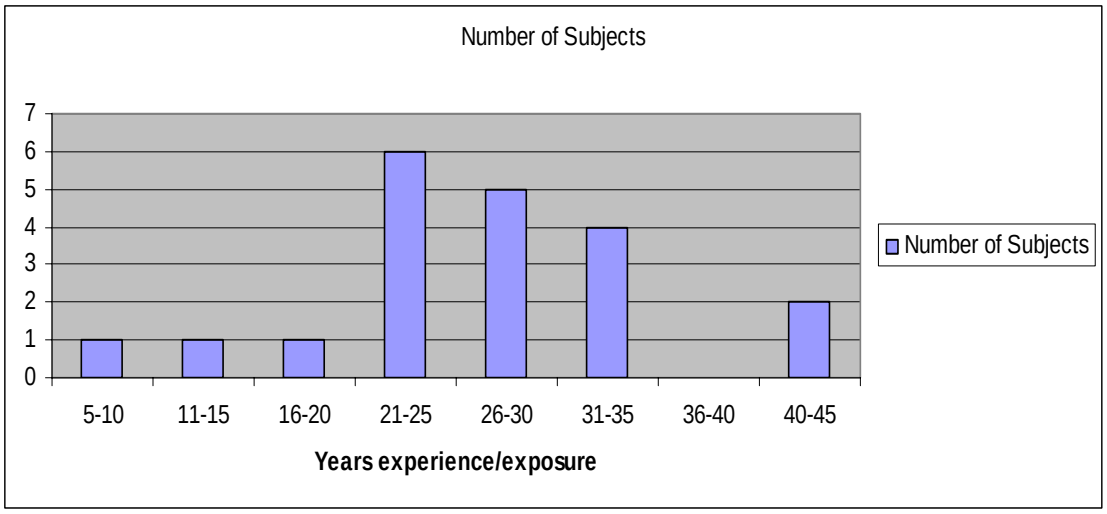

FIGURE 5.9: EXPERIENCE/EXPOSURE: MF/80 HZ/NON-SEDATED GROUP

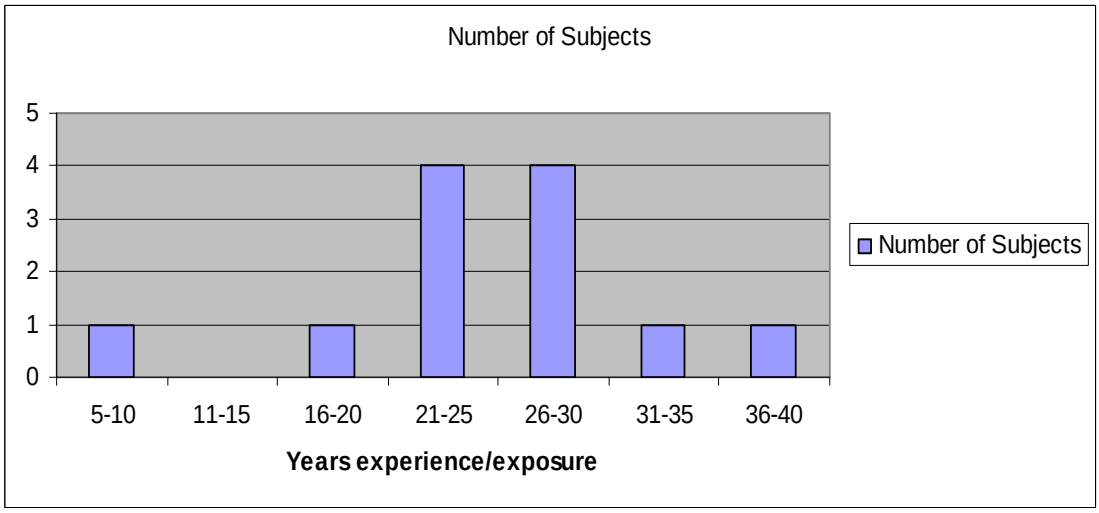

FIGURE 5.10: EXPERIENCE/EXPOSURE: SF/40 HZ/SEDATED GROUP

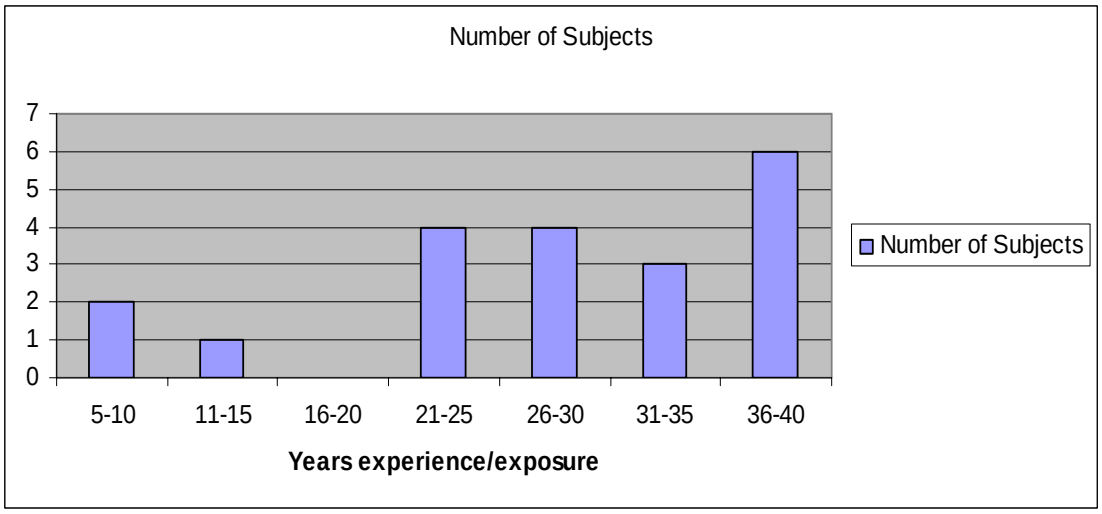

FIGURE 5.11: EXPERIENCE/EXPOSURE: MF/80 HZ/SEDATED GROUP

5.5.4.5 Experience of pseudohypacusic group

The group of mine workers with pseudohypacusis consisted of 29 subjects, distributed by experience, as can be seen in Figure 5.12 below.

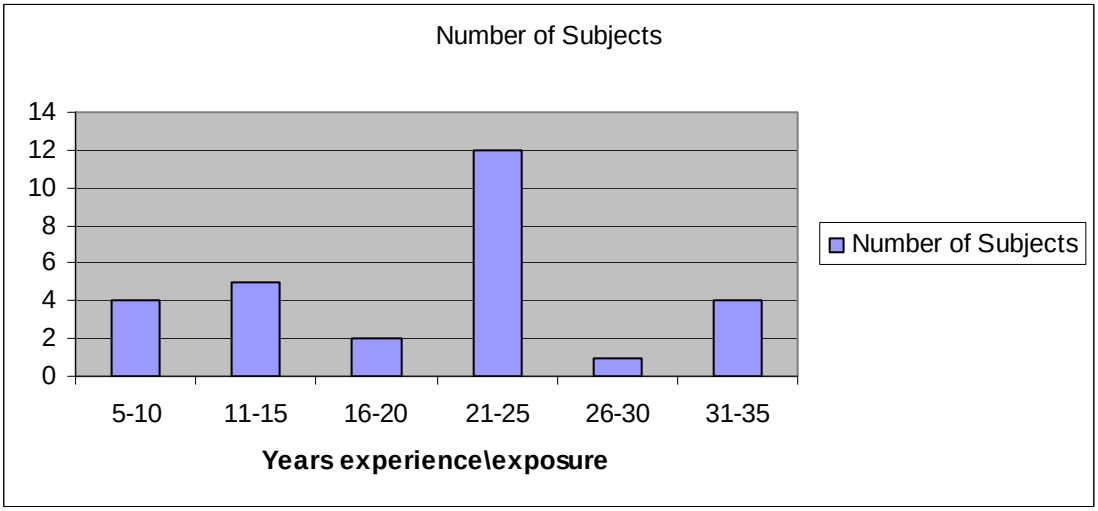

FIGURE 5.12: EXPERIENCE/EXPOSURE: PSEUDOHYPACUSIC GROUP

5.6 MATERIAL AND APPARATUS

The apparatus used in this study to obtain the research questions was the following:

5.6.1 THE MATERIAL AND APPARATUS USED FOR SUBJECT SELECTION

- Otoscopic examinations were performed using a **Heine Mini 2000** otoscope.
- Tympanometry was performed with a **GSI 33 middle ear analyser** and a **Beltone 2000 immittance tester**, both of which were calibrated (certificates in Appendices H and I) according to IEC 1027 regulations.
- Pure-tone audiometry (air- and bone-conduction) was performed by audiologists using a **Madsen OB 822** and **GSI 60 diagnostic audiometers.** This equipment was calibrated in accordance with SABS 0154-1 & 2 for pure-tone audiometers (the calibration certificates are appended as Appendices J and K).
- Diagnostic audiometry was performed in acoustically-treated test enclosures, calibrated in accordance with SABS 0182-1998 (the background noise certificates are appended as Appendices L and M).
- The patient files of the mine workers were perused at the Occupational Health Centres. The files were used to verify the participants' number of years of exposure and the use of ototoxic drugs and to obtain previous screening audiograms.
- A Case History questionnaire (see Appendix G) was used to exclude all other possible causes of sensory neural hearing loss and record all experimental procedures.

5.6.2 THE MATERIAL AND APPARATUS USED FOR DATA COLLECTION

5.6.2.1 Pure-tone testing

Pure-tone thresholds were obtained using the same calibrated audiometers and acoustic enclosures as detailed in the preceding section, that is a **Madsen OB 822** and a **GSI 60.** The calibration certificates are appended as Appendices J and K.

5.6.2.2 MF-ASSR testing

MF-ASSR responses were recorded using a multiple auditory steady state response system (MASTER), a Windows-based test and a data acquisition system developed by the Bio-logic Systems Corporation (2002). The MASTER system includes both software and hardware and is run using a personal computer. Bio-Logic's Navigator Pro TM unit performed the necessary analogue-to-digital and digital-to-analogue conversions, including the production of the stimulus output to earphone inserts and the gathering of the electroencephalogram input from the electrodes. The Navigator Pro was connected to the computer's serial port in order for the RS-232 communication protocol to be used. The computer hardware specifications were the following:

COMPUTER SYSTEM:

- an IBM-compatible 166 MHz Pentium computer
- 64 MB of RAM
- a 150 MB hard disk
- a Windows-compatible mouse
- a Windows 98 Operating system
- a 1.44 Mb 3,5" floppy disk drive

The installation and operation of the MASTER system requires a minimum of 20 MB free space on the hard drive (Bio-logic Systems Corporation, 2002).

PRINTING DEVICE:

- a Windows 98-compatible printer (Hewlett Packard DeskJet 840C).

OTHER HARDWARE:

- a Navigator Pro TM EP unit and accessories.

Disposable ear probe tips were supplied by Bio-logic Systems Corporation. The electrodes were latex-free and made of hypoallergenic material.

ASSR measurements were obtained in a calibrated environment, for which calibration certificates are supplied in Appendices L and M.

5.6.2.3 Single frequency ASSR testing

SF-ASSR data were collected using a GSI Audera system, manufactured by Grason-Stadler. The Audera system comprises:

- a notebook computer system with a Pentium II 200 MHz processor, 256 MB of RAM, a 5 GB hard disk, a 1,4 MB 3,5" diskette drive and pointing device (mouse/touch pad), running Windows XP;
- a USB connector;
- Audera software;
- an Audera unit;
- an Audera amplifier;
- electrodes; and
- GSI tip-50 inserts earphones with disposable ear tips.

Two Audera systems were used, a Beta prototype and a commercial production unit, because Grason-Stadler's South African agent (HASS) lent the equipment to the researcher and it was not possible to keep it on loan for the entire three-

month experimentation period. The Beta unit was a single channel instrument, requiring the researcher to switch channels after testing each ear.

5.6.2.4 Data preparation

Data preparation was performed using Excel for Windows 1998 (Levin, 2003).

5.7 DATA COLLECTION PROCEDURES

Three sets of data were collected from each subject in the co-operative noise-induced hearing loss group (Phase 1), namely a pure-tone air-conduction test (500, 1 000, 2 000, 3 000, 4 000 Hz), ASSR threshold estimates at the same frequencies and the test duration for each ASSR procedure. Data from each subject were collected on the same day, whenever possible starting with pure-tone testing (which also served as a subject selection procedure). Audiologists performed data collection procedures either at the Phumlani Occupational Health Centre in Randfontein, or at the Driefontein Occupational Health Centre in Carletonville. Recording was done in calibrated sound environments.

For the pseudohypacusic group of 29 subjects (Phase 2), four sets of data were obtained. These included two pure-tone air-conduction threshold tests at 500, 1 000, 2 000, 3 000, 4 000 Hz (ascending technique) followed by thresholds obtained at the same frequency, but using a descending method, SF-ASSR threshold estimates at the same frequencies, using a 40 Hz modulation rate and, lastly, the time required for testing.

5.7.1 PURE-TONE AUDIOMETRY

Pure-tone audiometry was performed during subject selection and data collection procedures, at 500, 1 000, 2 000, 3 000, 4 000 Hz, in line with Instructions 168 and 171 (Workmens' Compensation Commissioner, 1995 and 2000). These frequencies were selected since they are used for evaluations of fitness and

compensability. These thresholds were also used as a basis for comparison with ASSR thresholds. The pure-tone average from the audiogram was required to be in excess of 25 dB, to confirm potentially compensable abnormal hearing. In the pseudohypacusic group, the two pure-tone tests confirmed pseudohypacusis when they demonstrated a discrepancy of 15 dB or more between the two tests.

Pure-tone audiometry was performed using descending steps of 10 dB and ascending steps of 5 dB, with a 50 per cent positive response at the same level taken as the threshold, in accordance with the criteria of Stach (1998). Thresholds were determined first for the left and then for the right ear and were recorded on audiograms attached to the Case History questionnaire form (see Appendix G).

5.7.2 MF-ASSR DATA COLLECTION

Two groups of subjects were tested using a dichotic MF-ASSR technique, one without sedation and the other with sedation, to obtain threshold estimates at 500, 1 000, 2 000, 3 000, 4 000 Hz. Multiple amplitude moduated tones were selected with the carrier frequencies modulated between 80 and 110 Hz. It is important to note that a 40 Hz modulation is not available in multiple frequency test systems. Carrier frequencies were spaced at least one octave apart in line with suggestions by Perez-Abalo *et al.* (2001), and four frequencies were evaluated (dichotic) for each ear. Previous studies have indicated that a modulation rate of 80 to 110 Hz is appropriate for adults and that there are no significant differences between results using single- and multiple-frequency techniques (Lins & Picton, 1995). Time efficiency could also be evaluated in this way, since the design of the experiment left options for comparing the time required for using single- and multiple-frequency techniques. The carrier frequency, starting intensity and the size of the decrements (5 or 10 dB steps) were selected by the researcher, after which the computer directed the test procedure.

In the sedated group, 10 mg of Valium was administered after informed consent and medical clearance had been obtained. A medical doctor was present on the same premises to supply medical back-up or assistance if it were to be needed, and testing commenced one hour after the medication had been administered, to allow time for the medication to be absorbed. Subjects were transported back to their hostels and only reported for work the following day.

An electrode skin-preparation swab coated with Nuprep (an abrasive paste) was used to clean the areas where electrodes were to be affixed. Once the electrode sites had been cleaned, the skin was dried with a gauze pad to remove any residue, and disposable self-adhesive snap electrodes supplied by Biologic were affixed to the skin. Electrode impedance was immediately confirmed to be below five kilo-ohms, with no differences greater than two kilo-ohm between electrodes (Bio-logic Systems Corporation, 2002).

The electrodes were placed as followed:

- on the mastoid process – test ear
- on the mastoid process – (reference) contra-lateral to the test ear
- high on the forehead as recommended by Bio-logic Systems Corporation (2002)

Earphone probes were then inserted, using an appropriately sized disposable ear tip in accordance with the size of the subject's ear canal. The ear tip was securely coupled to the probe and fully inserted into the ear canal, to ensure proper stimulus delivery. In addition, correct cable connections were confirmed to prevent any juxtaposition of results for the right and left ears.

The test parameters used during this multiple frequency ASSR procedure were the default values as determined by the software supplied by Bio-logic System Corporation (2002).

The subject was asked to lie still, to relax or sleep and to keep his eyes closed. A pillow was provided for support to prevent any myogenic noise from impacting on the data collection when modulation frequencies between 80 and 100 Hz were used (Bio-logic Systems Corporation, 2002). Testing was performed in a sound-proof booth and the air conditioning in adjacent rooms was switched off, as were all telephones and cell phones. In addition, the door to the adjacent test room was closed, and visual distractions were minimised by switching off lights in the booth and the adjacent room. Before testing commenced, electrode impedance was re-confirmed. The audiologist was positioned in an adjacent room and had visual contact with the subject through a window in the test booth.

To ensure safety, power to the system was never switched on or off while a subject was connected to the system. Threshold determination occurred within a hearing level range of -20 to 120 dB, and the software warned the researcher when very high intensities were selected.

The software recorded the test data, providing for an exact measurement of the time taken for each subject. Electrophysiological thresholds were eventually determined from the responses obtained, based on a requirement for a less than 5 per cent chance that the subject's response might be attributable to chance (f-ratio statistics at a 0,05 level of confidence). The electrophysiological thresholds were eventually converted to pure-tone thresholds by subtracting 10 dB to predict a conventional audiogram, Guidelines on estimating a pure-tone thresholds were requested by the researcher in a personal communication with Bio-logic (Bio-logic, Systems Corporation, 2002).

- **Carrier frequencies**

  The default protocols were selected in order to obtain thresholds (four per ear) at 500, 1 000, 2 000, 3 000, 4 000 Hz. Default protocols prevented

testing at all the frequencies required in a single stimulation sequence, thereby requiring more than one set of stimulus presentations.

- **Modulation frequencies**

The modulation frequencies used were as indicated in Table 5.3

Table 5.3: MODULATION FREQUENCIES USED BY MASTER

CF	500 Hz	1 000Hz	2 000Hz	3 000Hz	4 000Hz
Modulation frequency	86.914Hz	89.844Hz	91.797Hz	83.008Hz	94.727Hz

The amplitude modulation percentage of the carrier frequency was set at 100 per cent and the frequency modulation percentage was set at 10 per cent (per side).

- **Number of sweeps**

The number of sweeps the MASTER runs per subject and per test threshold was set to 32 sweeps per test in accordance with the recommended protocol (Bio-logic Systems Corporation, 2002).

- **Epochs per sweep**

The number of epochs collected per sweep before the fast fourier transform (FFT) was performed was set at 16. Data transmitted to the FFT represented an averaged response from the subject, obtained from a running sum of all the sweeps that were recorded, divided by the number of sweeps collected.

5.7.3 SINGLE FREQUENCY DATA COLLECTION

Single frequency data collection procedures using the GSI Audera (Grason-Stadler) were applied to a group of sedated mine workers with noise-induced

hearing loss, as well as to two groups of subjects with noise-induced hearing loss who were not sedated. This allowed comparisons to be made to determine the most advantageous "state of consciousness" during ASSR testing. The two non-sedated groups were compared by using different stimulation rates (40Hz and 80Hz). Both of these rates had previously been found to provide reliable estimates of pure-tone thresholds during previous research.

Thresholds were required for 500, 1 000, 2 000, 3 000, 4 000 Hz, to allow comparisons of the single frequency ASSR, multiple frequency-ASSR and pure-tone thresholds. ASSR thresholds were obtained using both ascending and descending threshold-seeking procedures, starting at a hearing level of 40 dB, as with behavioural testing, and increments and decrements of 10 dB were used to limit the testing time. Single frequency ASSR tests were performed immediately after pure-tone testing, to ensure that all the procedures were completed on the same day. For sedated subjects, one hour was allowed for the absorption of the 10 mg of Valium, with the same provisions for consent and medical support met as for multiple frequency testing (again same-day testing was not always possible).

Electrodes were placed according to Grason-Stadler's specifications, as follows:

- the Audera Beta version: on the left and right ear lobes and high on forehead
- the Audera Commercial version: on the left and right ear lobes, high on forehead and low on forehead (the extra electrode allows clinicians to perform ABR testing as well).

Figure 5.13 illustrates the electrode placement for the Audera system.

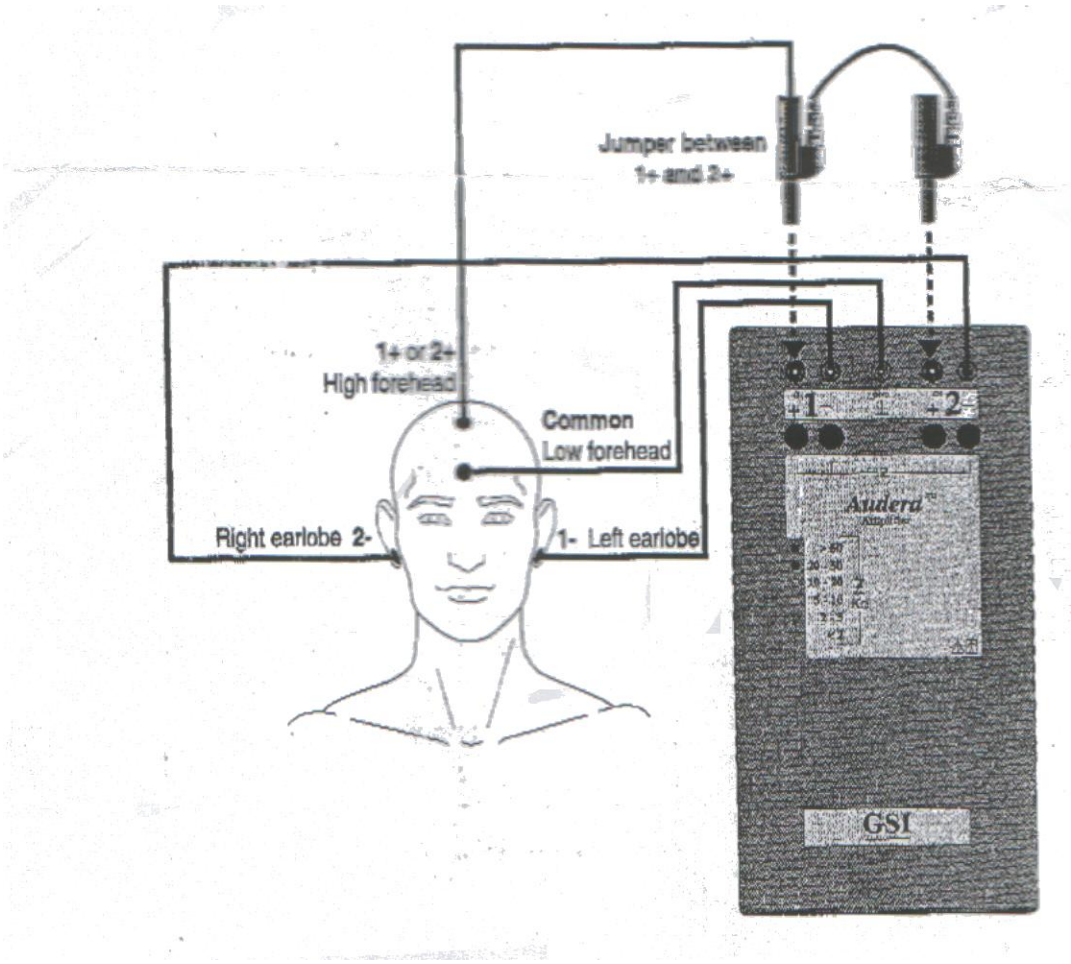

FIGURE 5.13: AUDERA ELECTRODE PLACEMENT (HASS: SOUTHERN AFRICA)

The same skin preparation procedures were used as for MF-ASSR tests before affixing re-usable electrodes (supplied by Grason-Stadler) with conductive gel (Elefix) and electrode tape. An electrode impedance of five kilo-ohms or lower was confirmed, and earphone inserts of an appropriate size were selected and fitted snugly into the external auditory meatus. After each test, the electrodes were removed and thoroughly cleaned in soapy water with a soft brush.

Instructions to the subjects and management of the test environment were similar to those for multiple frequency testing, in that subjects were asked to lie down, relax or sleep and to keep their eyes closed. Electrode impedance was re-

confirmed once the subject was lying down, and the audiologist was positioned in an adjacent room. Environmental noise was controlled in the same way as for multiple frequency tests.

The testing and data collection parameters were the following:

- **Carrier frequencies**

Carrier frequencies of 500, 1 000, 2 000, 3 000 and 4 000 Hz were used to allow comparisons between single frequency and multiple frequency estimated thresholds. With the Audera commercial version, it was possible to test all the above frequencies whereas with the Beta version the test software made no provision for the testing of 3000 Hz.

- **Modulation frequencies**

Two modulation frequencies were compared, namely, 40 Hz (awake) and 80 Hz (asleep).

- **FM and AM modulation**

The modulation rates used were the default values of 10 per cent for frequency modulation and 100 per cent for amplitude modulation.

- **Number of samples**

A total of 64 samples were taken per carrier frequency and hearing level set, for example, 1 000 Hz at 30 dB. The number of samples was specified by algorithms provided by the manufacturer.

- **Statistical measures**

For each electroencephalogram sample, the magnitude and phase of the electrical activity corresponding with the frequency of the tone modulation were quantified. Magnitude and phase information was shown as a vector in a polar plot, with the vector length corresponding with the magnitude and vector angle reflecting the phase or time delay between the tone modulation and the brain's response. Figure 5.14 illustrates a polar plot for a case where both the ear and the brain responded to a tone. The vectors in the plot are clustered, indicating a "phase-locked" brain response.

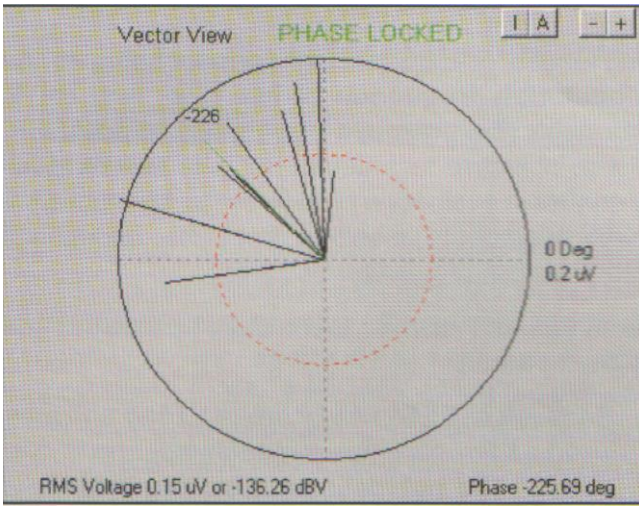

FIGURE 5.14: PHASE-LOCKED RESPONSE

Figure 5.15 shows the vectors obtained when the tone was presented at an inaudible level. Vector length varies and, most importantly, vectors are randomly distributed around the plot, indicating that there is no phase relationship between the electrical response and the tone modulation, in other words, no response.

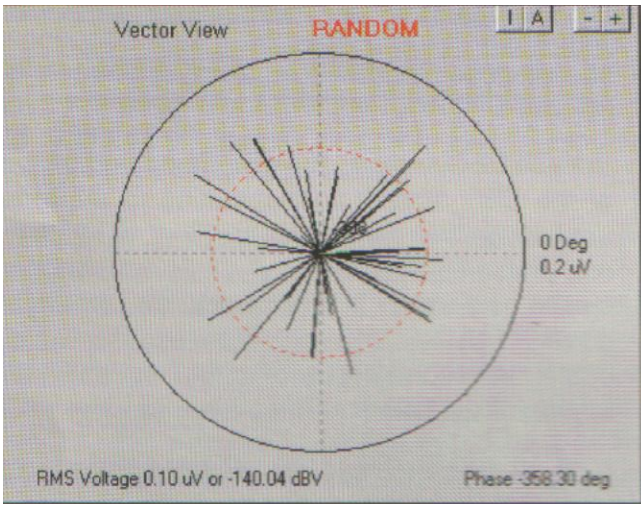

FIGURE 5.15: RANDOM RESPONSE

The identification of responses such as those illustrated in the preceding two figures as phase-locked or random was based on statistical analyses performed in real-time while samples were being recorded, and not on subjective visual assessments. A probability value of $p<0,03$ set the false-positive threshold for the single frequency technique at 3 per cent, and any trial contaminated with excessive noise was automatically terminated and labelled accordingly, as shown in Figure 5.16.

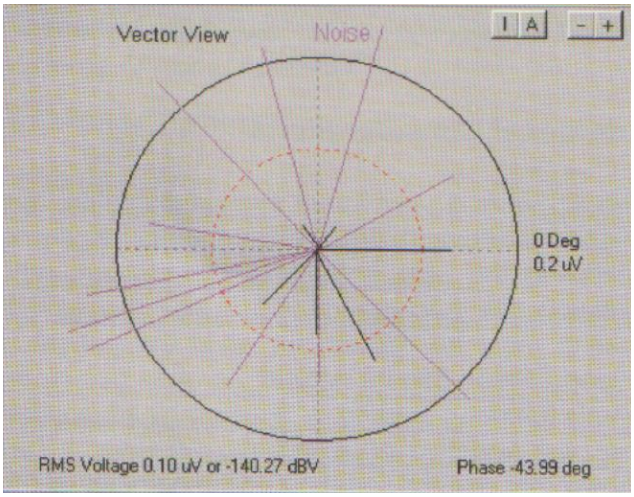

FIGURE 5.16: EXAMPLE OF RESULTS REJECTED DUE TO EXCESS NOISE

The results of all trials were plotted on a graph (Figure 5.17) with phase-locked results marked by an upward arrow to indicate that the ASSR threshold was better than the corresponding pure-tone threshold. Conversely, “random” or no-response results were marked with a downward arrow to indicate a lack of response. Thresholds were taken as the lowest level at which a “phase-locked” response was obtained for a given frequency.

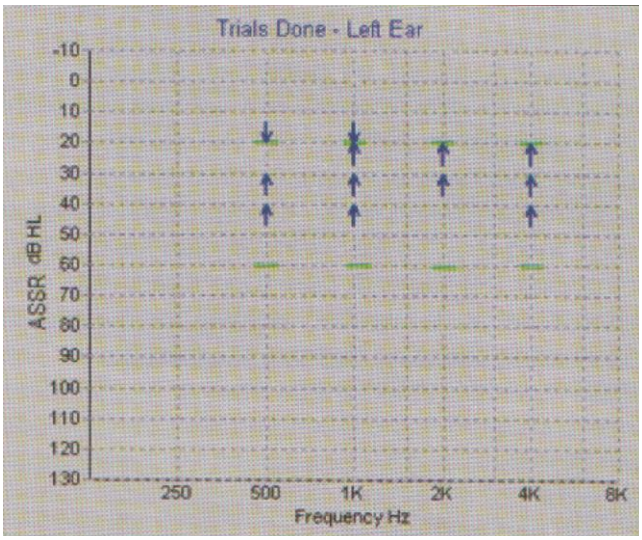

FIGURE 5.17: PLOTTED RESULTS OF TRIALS DURING AN ASSR TEST

Pure-tone thresholds were estimated on the basis of an algorithm developed from the research findings of Rance *et al.* (1995), as illustrated in the example in Figure 5.18, where the estimated pure-tone thresholds are presented objectively and without the clinician's input.

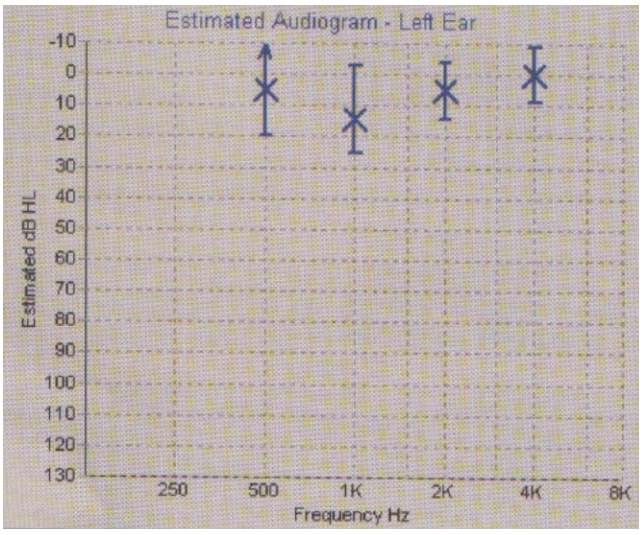

FIGURE 5.18: ESTIMATED AUDIOGRAM BASED ON THE ASSR RESULTS

Estimated pure-tone audiograms such as that shown in the preceding figure were compared with multiple frequency ASSR and conventional pure-tone thresholds.

5.8 DATA ANALYSIS PROCEDURES

A Microsoft Excel (2000) spreadsheet was used to collate data, which were then analysed using statistical measures developed by the Medical Research Council (Levin, 2002). Data analysis seeks to identify patterns in the data, in accordance with criteria determined by the test protocol used. This involves examining, sorting, categorising, evaluating, comparing, synthesising, contemplating and reviewing the data (Neuman, 1997). The following statistical procedures were applied:

- the sample t-test is a test that is used to compare different populations' means; and
- the two way analysis of variance is used for the analysis for experiments involving several independent variables (Wackerly, Mendenhall & Schaeffer, 1996).

5.9 SUMMARY

This chapter has described the research methods used in the acquisition of data in this study to determine the clinical value of ASSR methods in the audiological assessment of mine workers with sensory neural hearing loss and pseudohypacusis. The experimental design was discussed, after which the criteria and procedures for subject selection were detailed. The equipment used in the subject selection, data collection and data analysis were subsequently considered, after which data collection and analysis procedures were listed.

The next chapter presents the data obtained from the use of these methods.

CHAPTER 6

RESULTS

AIM

To present, discuss and interpret the results of the study and to evaluate these against the framework of the body of knowledge set out in the literature review.

6.1 INTRODUCTION

Roeser *et al.* (2000b) stated that the value of any diagnostic test depends on its ability to fulfil its intended purpose. The principal aim of the present study was to assess the clinical value of ASSR methods in the audiological evaluation of pseudohypacusic mine workers, particularly those with noise-induced hearing loss. Accurate estimations of hearing thresholds for the purposes of assessing compensability and fitness for work was the norm for deciding the clinical value of ASSRs.

The present study differs from previous work on ASSRs, in that it considered subjects with abnormal hearing, namely those with noise-induced hearing loss, a very specific form of sensory neural hearing loss (SNHL). Various protocols and instruments were compared in order, to identify the most appropriate and practicable procedure for assessing pseudohypacusic mine workers with noise-induced hearing loss. Because such individuals are often inclined to withhold co-operation during test procedures, the use of sedation in such testing was also evaluated. Another important criterion for evaluating the practicability of possible assessment procedures was the time required for testing, along with the overall cost of implementation of a procedure for the industry. This chapter is structured using the sub-aims of the study. These the sections are presented individually as they were in Chapter 5 (Sections 5.2.2.1 to 5.2.2.5).

The results are described and summarised using tables and figures. Consequently the results are discussed. Finally the findings are interpreted as suggested by Mouton (2001).

6.2 CO-OPERATIVE MINE WORKERS WITH NOISE-INDUCED HEARING LOSS (PHASE ONE)

6.2.1 SUB-AIM: TO COMPARE ASSR AND PURE-TONE THRESHOLDS IN A CO-OPERATIVE POPULATION OF ADULT MINE WORKERS WITH SENSORY NEURAL HEARING LOSS

In the assessment of the results the ASSR thresholds are compared to the relevant pure-tone thresholds in order to determine whether ASSR thresholds can predict pure-tone thresholds accurately. The norm used in this case was a 0 to 10 dB difference between any two threshold tests, which in clinical practice is generally seen as an acceptable inter-test difference (RMA guidelines, 2003).

In order to realise the aim it is thus necessary to determine what the difference is between pure-tone and ASSR thresholds for every individual subject as well as the mean difference in a whole experimental group. The significance of any differences was determined using statistical procedures (the sample t-test and two way analysis of co-variance).

All the subjects were required to have potentially compensable hearing loss and, thus, a binaural pure-tone average exceeding 25 dB over the range of 500, 1 000, 2 000 and 3 000 Hz (Workmen's Compensation Commissioner, 1995). As has already been mentioned the abnormal pure-tone thresholds obtained from subjects varied from mild through to severe hearing thresholds (see Chapter 5, p98). Because noise-induced hearing loss is sensory neural in nature, the subjects' hearing was most severely affected at the higher frequencies and, thus, some subjects had normal hearing at the lower frequencies. This finding was not anticipated but it was eventually included in the data thus providing a base line of normal hearing thresholds with which the ASSR thresholds could be evaluated as a starting point. A breakdown of

the pure-tone thresholds obtained for the 81 subjects has been given in order to enable some understanding of the nature and extent of noise-induced hearing loss and to indicate in what severity range of hearing loss the ASSR procedures were used (see Section 5.5.4.1).

The clinical value of ASSR thresholds was evaluated using the norm of a 10 dB inter-test variance, which is seen as acceptable in the mining industry (RMA guidelines, 2003). All the pure-tone thresholds obtained for the 81 subjects were compared to the ASSR thresholds obtained for the same subjects for both ears and at all the frequencies tested. The overall mean pure-tone threshold obtained for the frequencies tested in the group of 81 co-operative subjects was also compared to the overall mean ASSR threshold.

To gain further insight into the clinical value of ASSR thresholds an analysis was also done on how much ASSR thresholds differed from the pure-tone thresholds (for example, between 0 to 10 dB; 10 to 20 dB etc.).

Although the participating workers, had been selected because they have noise-induced hearing loss, it was found that the pure-tone thresholds obtained varied throughout the severity range from normal to severe hearing thresholds. The following figures (6.1 – 6.4) give an indication of the number of thresholds per frequency obtained in the normal, mild hearing loss, moderate hearing loss and severe hearing loss categories.

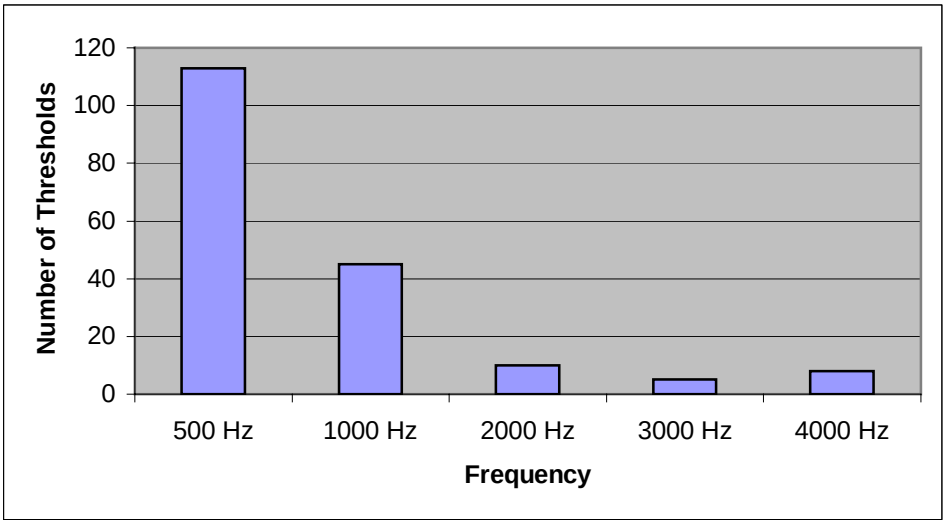

FIGURE 6.1 NUMBER OF NORMAL (≤25 dB) PURE-TONE THRESHOLDS FOR TEST FREQUENCY (n=181).

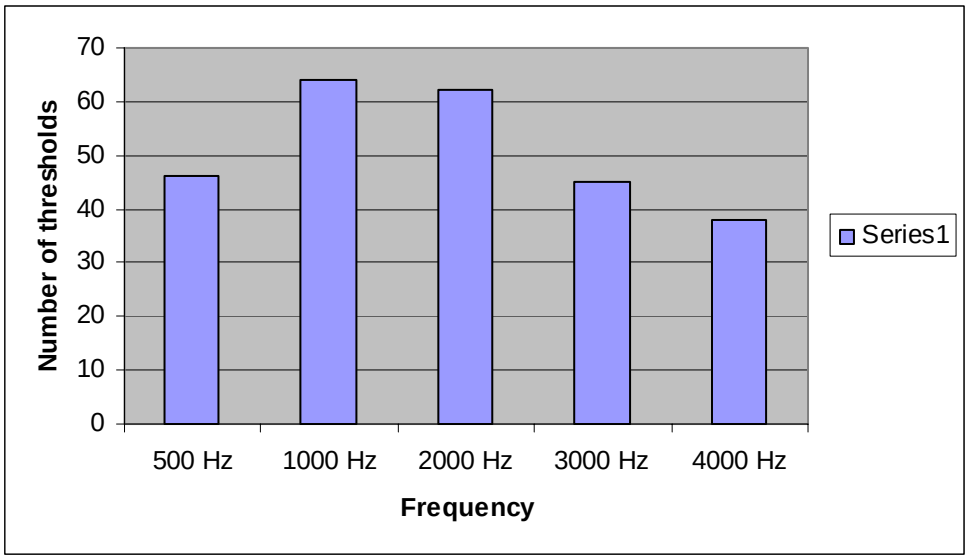

FIGURE 6.2 NUMBER OF PURE-TONE THRESHOLDS INDICATIVE OF MILD HEARING LOSS - PER FREQUENCY, (n=251)

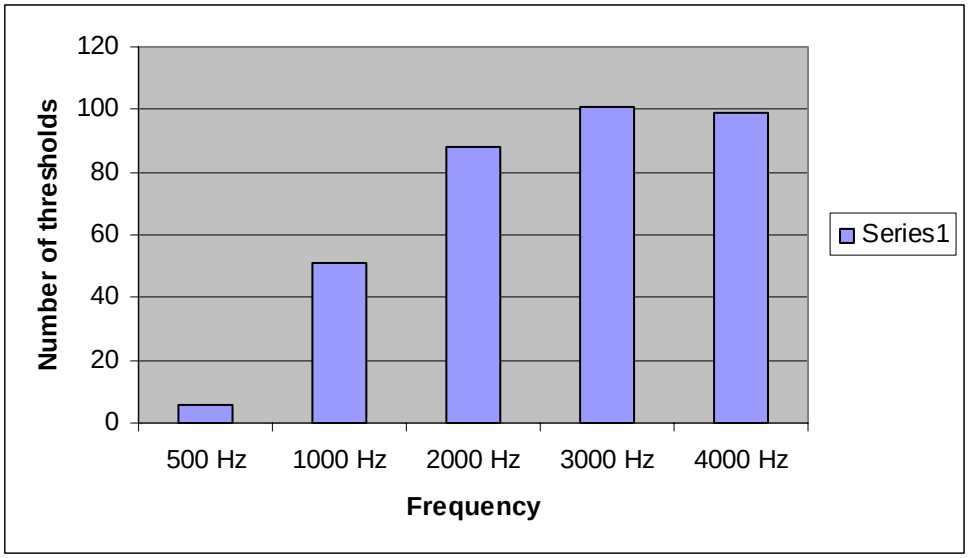

FIGURE 6.3: NUMBER OF PURE-TONE THRESHOLDS INDICATIVE OF MODERATE HEARING LOSS- PER FREQUENCY (n=345)

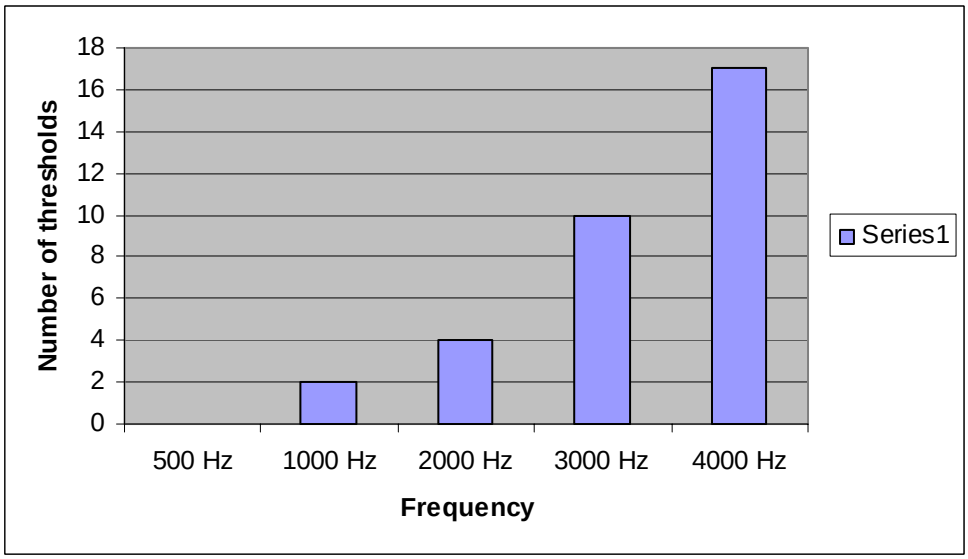

FIGURE 6.4 NUMBER OF SEVERE PURE-TONE THRESHOLDS- PER FREQUENCY (n=33)

As can be seen from Figure 6.1 the ASSR technique was unintentionally, tested in normal hearing thresholds (n=181). The known sloping character of noise-induced hearing loss makes the finding of the majority of normal thresholds in the 500 and 1000 Hz area an expected result. Mild hearing thresholds (n=251) (Figure 6.2) were obtained in subjects in all tested frequencies despite significant years of noise exposure (see Figures 5.7 to

5.11). Thresholds obtained in the moderate range were the highest in numbers (n=345) as seen in Figure 6.3. Significant moderate thresholds were obtained at 1 000, 2 000, 3 000, and 4000 Hz. It can be deducted that noise-induced hearing loss as seen in mine workers in the majority of cases presents as a moderate sensory neural hearing loss. Only a few (n=33) thresholds were obtained in the severe range as can be seen in Figure 6.4. From the above figures it can be concluded that the value of ASSR thresholds can be evaluated throughout the severity range of hearing loss, varying from mild to severe hearing loss. In Table 6.1 below the mean differences between ASSR- and pure-tone thresholds are highlighted.

TABLE 6.1: COMPARISONS BETWEEN ASSR AND PURE-TONE THRESHOLDS ACCORDING TO SEVERITY OF HEARING LOSS

FREQUENCY Hz	EAR	NORMAL HEARING 0-25 dB		MILD HEARING LOSS 26-40 dB		MODERATE HEARING LOSS 41-65 dB		SEVERE HEARING LOSS 66+ dB		P VALUE
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	
500	**Left**	4,22	13,93	3,75	10,41	5	0	-	-	0,99
1 000	**Left**	8,53	11,01	2,59	7,63	0,53	7,80	-	-	0,02
2 000	**Left**	-	-	8,54	11,75	-0,97	8,18	-2,5	3,54	0,00
4 000	**Left**	10,0	12,91	1,92	6,30	2,5	6,96	4	9,62	0,28
500	**Right**	9,79	15,74	3,57	10,82	2,5	3,53	-	-	0,33
1 000	**Right**	9,75	10,57	2,71	7,52	0,65	7,28	-5	0	0,00
2 000	**Right**	10	22,91	4,62	9,37	2,35	7,71	10	0	0,43
4 000	**Right**	3,33	5,77	0,42	7,53	1,84	7,66	5	21,21	0,85

From the above table it can be deducted that there is evidence that the sensitivity of ASSR estimates does depend on the category of hearing loss

(L, 1 000 Hz; L, 2 000 Hz; R, 1 000 Hz). The overall differences between ASSR- and pure-tone thresholds are greatest at normal hearing. These findings support that of numerous other researchers (Rance *et al.*, 1995; Sininger & Cone-Wesson, 1994; John & Picton, 2000 and Schmulian, 2002) that ASSR thresholds favour pathological ears. This finding has been explained due to the phenomenon of recruitment.

If all the pure-tone and ASSR thresholds of all the subjects in Phase 1 of the study (co-operative workers) were compared, it resulted in 810 pure-tone thresholds (81 subjects x 2 ears x 5 frequencies) that were compared with 542 ASSR threshold estimates (see Appendix N). The discrepancy in numbers was due to the fact that the Audera Beta (prototype) instrument failed to make provision for testing at 3 000 Hz, affecting 24 readings (12 subjects x 2 thresholds = 24), and that the Biologic instrument only had the capacity to determine eight thresholds at once, making it necessary to test one frequency separately, thereby extending what was already a lengthy procedure.

The specific comparison between pure-tone and ASSR thresholds will be set out in the following Tables 6.2 to 6.4 and in Figure 6.5.

TABLE 6.2 COMPARISON OF ASSR AND PURE-TONE THRESHOLDS BY TEST FREQUENCY

TEST FREQUENCY (HZ)	THRESHOLD ESTIMATION TECHNIQUE	MEAN THRESHOLD/SD (dB)	DIFFERENCE IN THRESHOLDS (dB)
Left ear			
500 Hz	ASSR	24,8/15,5 n=64	
	PT	21,38/11,70 n=81	3,42
1 000 Hz	ASSR	39,8/12,5 n=66	
	PT	37,06/13,14 n=81	2,74
2 000 Hz	ASSR	48,1/11,2 n=62	
	PT	45/10,61 n=81	3,1
3 000 Hz	ASSR	54,5/14,6 n=20	
	PT	48,50/12,60 n=81	6
4 000 Hz	ASSR	52,96/15,59 n=55	
	PT	50,13/14,16 n=81	2,83
Right ear			
500 Hz	ASSR	27,81/16,0 n=65	
	PT	20,43/10,65 n=81	7,38
1 000 Hz	ASSR	40/12,19 n=69	
	PT	35,19/13,39 n=81	4,81
2 000 Hz	ASSR	47,27/12,15 n=65	
	PT	42,19/10,96 n=81	5,08
3 000 Hz	ASSR	48/12,40 n=20	
	PT	47,43/11,52 n=81	0,57
4 000 Hz	ASSR	50,73/14,95 n=56	
	PT	51,06/14,20 n=81	0,33

Table 6.2 gives the mean pure-tone and ASSR thresholds for all the subjects (Phase 1: n=81). As mentioned before, the same number pure-tone and ASSR thresholds were not obtained. The differences between the mean ASSR and pure-tone thresholds vary from 0,33 to 7,38 dB (Table 6.2), which was well within the 10 dB variation that was taken to be an acceptable difference between two audiometric tests. The biggest difference was found in the right ear at 500 Hz.

TABLE 6.3: RESULTS FROM THE PURE-TONE AND ASSR TESTING OF LEFT AND RIGHT EARS

FIVE FREQUENCY MEAN FOR GIVEN EAR	THRESHOLD ESTIMATION TECHNIQUE	MEAN THRESHOLD (dB)	SD
Left ear	ASSR n=70	41,73	9,31
	PT n=81	40,41	8,21
Right ear	ASSR n=77	42,18	9,65
	PT n=81	39,26	8,14
Overall mean for both ears	ASSR n=78	42,40	8,91
	PT n=81	39,84	7,52

Table 6.3 compares thresholds from the ASSR (all procedures) and pure-tone testing for all the frequencies combined for the left and right ears respectively. It is again clear that the mean differences of the ASSR and pure-tone tests corresponded to within 10 dBs.

TABLE 6.4: MEAN DIFFERENCE BETWEEN ASSR ESTIMATES AND PURE-TONE THRESHOLDS (dB) PER FREQUENCY TESTED

FREQUENCY (Hz)	DIFFERENCE (dB)	DIFFERENCE (dB)
Ear:	**Left**	**Right**
500 Hz	4,14	8,20
1 000 Hz	3,53	3,97
2 000 Hz	2,66	3,75
3 000 Hz	4,75	-1,25
4 000 Hz	3,06	1,72
All frequencies	1,69	2,50

Table 6.4 indicates the differences between the mean thresholds from the ASSR- and pure-tone testing. On average all the ASSR and pure-tone thresholds obtained only differed 1,69 dB in the left ear and 2,50 in the right ear.

Another way to obtain an idea of the clinical value of ASSR tests, (the ability to predict pure-tone thresholds) is set out in Figure 6.5. The number of pure-tone and ASSR thresholds that corresponded within a range of 10 dB, 15 dB, 20, dB and 25 dB is illustrated in the following Figure 6.5.

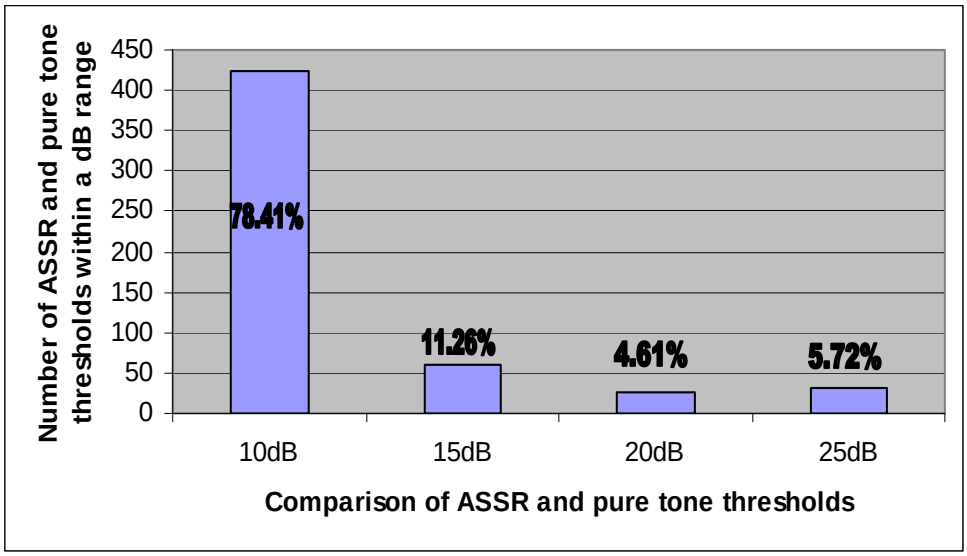

FIGURE 6.5: CORRELATION OF PURE-TONE AND ASSR THRESHOLDS

In the overwhelming majority (78, 41 per cent) of thresholds obtained, the ASSR and pure tone thresholds correlated within the 10 dB range as needed.

From the preceding three tables, it is apparent that the ASSR thresholds and pure-tone thresholds correlated within the acceptable 10 dB range (Workmen's Compensation Commissioner, 1995 and 2000), thus making ASSR testing a clinically acceptable measure to predict pure-tone thresholds. The largest difference of 8,2 dB occurred at 500 Hz for right ears, which corresponds with findings by other authors (John *et al*., 2001; Lins *et al.,* 1996; Schmulian, 2002; Herdman & Stapells, 2001). Rance *et al.* (1993) have described larger response amplitudes for higher carrier frequencies. This reduced ability to estimate lower frequency thresholds accurately has been explained as a result of an intrinsic jitter, where the activation pattern along the basilar membrane covers a larger area for lower frequency stimuli or lower carrier frequencies (Schmulian, 2002). Lins *et al*. (1996) also refer to the masking effect of background noise on 500 Hz steady-state stimuli. This explanation is possibly not relevant to the present study, since testing was done in an acoustically treated booth, as was also the case with the pure-tone testing.

The same authors also postulate that stimuli at 500 Hz may be masked by higher frequency signals during MF-ASSR testing. This could have affected the present study, since sensory neural hearing loss made it necessary to use high-intensity stimuli at the higher test frequencies. Another explanation is that the ASSR thresholds for the lower test frequencies, particularly 500 Hz, were the closest to normal hearing (172 normal thresholds). Many studies have indicated that ASSRs tend to favour abnormal hearing – that is a closer correlation with abnormal pure-tone thresholds as a result of recruitment. (John & Picton, 2000; Schmulian, 2002) (See Table 6.1).

To reduce test time, the present study used 10 dB intervals during threshold-seeking procedures for both the MF- and SF-ASSR tests, in accordance with accepted practice for auditory evoked potential methods (Picton *et al.*, 2003). SF- and MF- techniques allow the use of 5 dB steps to provide greater accuracy than that achieved in the present study, but it is important to note that the mean differences between the pure-tone and ASSR thresholds obtained here were smaller than those obtained in many previous studies (30-34 dB: Swanepoel, 2001; 8-18 dB: Lins & Picton, 1995; 28-34 dB: Aoyagi *et al.,* 1994). One explanation for the smaller mean differences in the present study is that ASSR instrumentation and algorithms have improved in recent years. During the course of this study the Audera equipment was upgraded from the Beta to the commercial version. John *et al.* (2001) have also noted better response detection with the introduction of mixed modulation methods, which were used in the present study.

This research strove to use an objective procedure- thus to avoid any influence by the clinician on the determination of thresholds. The only variables that could be manipulated by the clinician during MF-testing were the number of sweeps and the extent of averaging. Swanepoel (2001) and Schmulian (2002) have both noted the current lack of standards for the latter parameter, and have stated that more averaging is needed for stimuli with intensities near the threshold level. The Audera system, unlike the Biologic system, uses built-in algorithms to control the number of samples, thereby

eliminating any possibility that the clinician could influence this test parameter. Clearly, testing for clinical purposes should employ standardised sampling and averaging methods that are uniformly controlled by algorithms in the test system.

To summarise: the data indicate that ASSR thresholds can predict pure-tone thresholds to within 10 dB in more than 70 per cent of the cases and that the mean ASSR and pure-tone thresholds of 81 subjects correlated to within 1,69 and 2,50 dB for the respective ears (see Table 6.4).

The previously limited clinical validation of ASSR testing has been extended by the present study's demonstration of ASSR thresholds that were well within 10 dB of pure-tone thresholds, for a large population of subjects with noise-induced hearing loss (sensory neural in nature) across the entire severity range.

As previously mentioned, 536 ASSR thresholds were obtained in comparison to 810 threshold results for pure-tone testing, due to shortcomings in both the Audera Beta and Biologic systems. South African compensation assessments require 10 thresholds (RMA guidelines, 2003) but the Biologic system can only determine eight thresholds in a single test run. Subject-related factors such as noise from body movement and myogenic noise were also found to influence the difference in thresholds obtained as mentioned above. Influences such as movement, fidgeting, coughing and sneezing accounted for some of the shortfall in ASSR thresholds, as was found in previous studies (Aoyagi *et al*., 1994) where test procedures were also lengthened by such interventions. ASSR tests were performed with the clinician in an adjacent room and, although visual contact was possible through the booth's window, the booth and test room were both darkened, limiting the audiologist's awareness of coughing, sneezing and movement by the subject. The system identified any substantial occurrence of noise artefacts, but the audiologist had no direct control over this potential source of error. This raises the possibility that the clinician's presence in the same room could have limited

subject movement and fidgeting, as well as any deliberate disregarding of instructions on the part of unco-operative subjects.

The preceding presentation and discussion of results indicates that ASSR testing is a reliable and accurate method for objectively estimating frequency-specific hearing thresholds and that it can be successfully applied as an alternative to pure-tone testing for adults with noise-induced hearing loss. The present results have also confirmed previous findings that ASSR methods are not influenced by the age of the subject (Picton, 1991) and that ASSR thresholds are more accurate in pathological ears (Schmulian, 2002).

In order to analyse the clinical usefulness of ASSR testing further, various test protocols, including the effect of sedation, are considered in the sections below.

6.2.2 TO COMPARE THE CORRELATION OF MULTIPLE-FREQUENCY (DICHOTIC) AND SF-(MONOTIC)-ASSR STIMULATION METHODS IN ESTIMATING PURE-TONE THRESHOLDS IN A MINE WORKER POPULATION

Single-frequency (monotic) stimulus tests were performed on 41 subjects using the Audera system (single-frequency). Multiple-frequency (dichotic) stimulus testing of 40 subjects was done using the Biologic Master, which provided for simultaneous stimulation at four test frequencies in each ear. Table 6.5 indicates the average number of test frequencies at which a threshold was determined using each technique.

TABLE 6.5: AVERAGE NUMBER OF FREQUENCIES COMPLETED USING SF-AND MF- TESTING PER SUBJECT

STIMULATION TECHNIQUE	NUMBER OF FREQUENCIES	PAIRED "t" AND "p" VALUE
Single-frequency (Audera)	6	t =-2,39
Multiple-frequency (Biologic)	7,4	p>0,0193

As can be seen from the preceding table, the Biologic completed more threshold estimates (7,4 versus 6), possibly due to its ability to complete eight frequencies simultaneously. In addition the Audera Beta prototype (single-frequency method) also did not provide for testing of 3 000 Hz which placed this test procedure at a disadvantage. The difference in the number of threshold estimates obtained was statistically significant with a p-value of 0, 01.

Table 6.6 indicates the average time taken for the two stimulation techniques, independent of the number of thresholds obtained, while Table 6.7 shows the time taken normalised for the number of thresholds obtained.

TABLE 6.6: TIME TAKEN FOR SF- AND MF-TESTS, INDEPENDENT OF THE NUMBER OF FREQUENCIES COMPLETED

STIMULATION TECHNIQUE	TIME (MINUTES)	PAIRED "t" AND "p"VALUES
SF (Audera)	50,44	t= -7,19
MF (Biologic)	85,4	p=0,00

TABLE 6.7: TIME TAKEN FOR SF- AND MF -TESTS, NORMALISED FOR THE NUMBER OF FREQUENCIES COMPLETED

STIMULATION TECHNIQUE	TIME (MINUTES)	PAIRED "t" AND "p" VALUES
SF (Audera)	51,56	t=-6,56
MF (Biologic)	84,18	p=0,000

The two preceding tables show that the stimulation technique used (monotic SF- or dichotic MF) is a highly significant factor (p=0, 00 in Table 6.6 and 6.7), with the SF- technique being the more time-efficient. This finding contradicts previous findings (Perez-Abalo *et al*., 2001). Several researchers have suggested that it would take the same time to test eight different frequencies

using the MF-technique as for a single frequency using the SF-method. One possible explanation for this apparent anomaly is that most previous studies looked at subjects with normal hearing, implying that threshold-seeking procedures would start at 40 dB, after which only two or three descending steps would be required. For subjects with hearing loss, a multi-frequency technique would start at 40 dB and, after obtaining no response, stimuli would then be presented at higher intensities thereby lengthening the test procedure.

It must also be considered that the SF-technique employs the 40 Hz response, which is more robust in adults than in children. The use of higher stimulation rates, as with the Biologic system, is specifically intended to address the 40 Hz response's sensitivity to infants' maturation and state of consciousness, which was not a concern in the present context.

Furthermore, there are discrepancies in previously reported test times for MF-procedures. Herdman and Stapells (2001) have reported an average time of 83 minutes, three times longer than the 21 minutes reported by Perez-Abalo *et al.* (2001), while Swanepoel (2001) has reported test times between 15 and 31 minutes. It is also relevant to note that Perez-Abalo *et al. (*2001) and Swanepoel (2001) both tested normal hearing subjects. Herdman and Stapells (2001) used 5 dB increments to determine thresholds which could explain the longer test time.

Testing during the present study took an average of 84,18 minutes but there are no standards governing the number of sweeps and averages obtained, and it would therefore be invalid to compare the present test times directly with those reported previously. Stimulation at a low intensity increases the number of averages required and, thus, the recording time, indicating a need for internationally accepted standards for averaging methods and algorithm specifications, particularly for clinical applications. Although the SF-technique used in the present study eliminated any influence by the audiologist on averaging, the MF-technique allowed the number of sweeps and averages to

be selected, indicating that the need for objectivity was better met by SF-ASSR testing.

A further disadvantage of the MF-stimulation technique for individuals with sensory neural hearing loss is that this condition is progressively more severe at higher frequencies, which means that some subjects could have normal hearing at the low frequencies despite severe or even profound hearing loss at higher test frequencies. This made it impossible to select a uniform intensity protocol for the 500 to 4000 Hz range. A level of 100 dB, while possibly suitable for higher frequencies, would have been dangerously loud at a frequency of 500 or 1 000 Hz, making it necessary to use the MF- technique in what was essentially a SF-mode, by first testing at 1 000, 2 000 and 4 000 Hz, and then testing at 500 Hz separately. This partially accounts for the longer times required for the MF-testing.

Table 6.8 indicates the differences in prediction value of the pure-tone thresholds between the SF- and MF- techniques and the levels of significance of the data.

TABLE 6.8: DIFFERENCES IN SENSITIVITY BETWEEN THE SF- AND MF-STIMULATION TECHNIQUES

STIMULATION TECHNIQUE	MEAN DIFFERENCE BETWEEN ASSR AND PT THRESHOLDS		
	500 Hz	500 Hz	1 000 Hz
	Left	Right	Right
SF	7,69	8,39	6,13
MF	11,71	16,66	8,92
t-test	-1,85 p≥0,0694	-3,34 0,0014	-1,83 p≥0,072

From the table it can be seen that SF-testing yielded more accurate estimates of the thresholds than the MF-methods, particularly at the low frequencies. The SF-technique's higher sensitivity may be attributable to the high

stimulation levels required, as mentioned previously. Lins and Picton (1995) found no significant differences in the response amplitude between the MF- and SF-methods, provided intensity was at low-to-moderate levels. John and Picton (2000) also caution against the dangers of high-intensity stimulation.

From the above discussion it can be deducted that, although the SF-method completed fewer threshold estimates in comparison to the MF-method, that the SF-procedure was more accurate in determining thresholds and that it took less time to obtain a threshold. This last finding appears to contradict what one would intuitively expect namely that it would less time to obtain eight thresholds tested simultaneously.

6.2.3 TO COMPARE DIFFERENT MODULATION FREQUENCIES' EFFECTIVENESS IN ESTIMATING PURE-TONE THRESHOLDS

28 subjects were tested using a 40 Hz stimulation rate (the Audera-awake protocol), while 52 subjects underwent testing with the higher rate of 80 to 110 Hz (the Audera asleep protocol and Biologic MASTER). The results are set out in Table 6.9 and 6.10.

TABLE 6.9: TIME TAKEN FOR 40 HZ AND 80-110 HZ TESTS, INDEPENDENT OF NUMBER OF FREQUENCIES COMPLETED

STIMULATION TECHNIQUE	TIME (MINUTES)	PAIRED "t" AND "p"VALUES
40 Hz (Audera)	50,44	t= -7,19
80-110 Hz (Biologic)	85,4	p=0,00

TABLE 6.10: THE TIME TAKEN FOR SF- AND MF-TESTS, NORMALISED FOR THE NUMBER OF FREQUENCIES COMPLETED

STIMULATION TECHNIQUE	TIME (MINUTES)	PAIRED "t" AND "p" VALUES
40 Hz (Audera)	51.56	t=-6,56
80-110 Hz (Biologic)	84.18	p=0,000

From these tables it can be seen that the average testing time (normalised for the number of frequencies evaluated) was 33 minutes longer using the 80 to 110 Hz stimulation rate than with a rate of 40 Hz, but there was statistical evidence in only one frequency that the SF-method was more accurate in determining pure-tone thresholds (500 Hz, see Table 6.8; p=0.001) (The single-frequency technique used a 40 Hz stimulation rate and the multiple-frequency method a 80 to 110 Hz rate, therefore there is referred to Table 6.8).

Stapells *et al.* 1984 have found the amplitude of auditory evoked potential responses to be two to three times greater with a 40 Hz stimulation rate than with a 10 Hz rate while Dobie and Wilson (1998) have also found 40 Hz to be the stimulation rate of choice for alert or sedated adults. The stimulation rate of 40 Hz was also favoured in the present research. Another research team that came to the same conclusion was Rickards and De Vidi (1995) who found the 40 Hz rate to be more suitable for use in adults. These researchers explain the finding by stating that the 40 Hz response did not require compensation or allowance for maturational effects. Other researchers have investigated the use of other stimulation rates to overcome the effect of wakefulness on the 40 Hz response (Herdman & Stapells, 2001; Lins *et al*., 1995). Difficult-to-test populations mainly consists of young children and infants, which may help to explain the move towards higher stimulation rates that are less affected by sleep, sedation and maturation (in these populations).

6.2.4 TO DETERMINE THE EFFECT OF SEDATION ON THE ASSR TEST'S ABILITY TO ESTIMATE PURE-TONE THRESHOLDS

28 non-sedated subjects were tested using the SF-method without sedation, while 13 were tested by the same method while sedated. For the MF-ASSR tests, 20 subjects were sedated and an equal number were not, to determine the effect of this factor on the sensitivity and test time. The significance of the differences between the two methods is set out in Table 6.11 (raw data is seen in Appendix N).

TABLE 6.11: THE SIGNIFICANCE OF TIME COMPARISONS OF MF- AND SF-TECHNIQUES WITH AND WITHOUT SEDATION

TECHNIQUE	T-TEST	P VALUE
SF	1,86	0,19
MF	2,18	0,15

From the above table it is clear that time comparisons between both SF- and MF-testing yielded no significant difference between the test times for sedated and non-sedated subjects (p=0,19 and 0,15)(Table 6.11).

In order to evaluate the effect of sedation further, comparisons were also made between the accuracy of the threshold estimates with and without sedation.

Results are set out in Table 6.12 and 6.13 below.

TABLE 6.12: SIGNIFICANCE OF SENSITIVITY DIFFERENCES BETWEEN SEDATED AND NON-SEDATED SF-ASSRs

FREQUENCY (HZ)	t-TEST	p-VALUE
LEFT EARS		
500	0,4956	0,6251
1 000	-0,9221	0,3660
2 000	-1,0345	0,3132
4 000	0,7614	0,4553
RIGHT EARS		
500	0,1028	0,9190
1 000	1,1867	0,2475
2 000	-0,2813	0,7811
4 000	-0,6505	0,5221

TABLE 6.13: SIGNIFICANCE OF SENSITIVITY DIFFERENCES BETWEEN SEDATED AND NON-SEDATED MF-ASSRs

FREQUENCY (HZ)	t-TEST	p-VALUE
LEFT EARS		
500	1,1208	0,2698
1 000	1,3545	0,1840
2 000	0,1524	0,8798
4 000	0,8331	0,4118
RIGHT EARS		
500	0,8687	0,3911
1 000	1,9412	0,0603
2 000	0,9459	0,3509
4 000	0,9461	0,3535

The same lack of significant differences was found if attention was focused on the threshold estimation accuracy in SF- and MF-techniques when they were compared in terms of the sensitivity with and without sedation. The preceding tables indicate no significant effect from sedation on the sensitivity or test time for SF- and MF-testing (all the p values were higher than 0, 05) and, hence, there is no reason to sedate adults, provided they co-operate and limit their movement during the test procedures. Other researchers have found that sedation significantly diminishes the amplitude of the 40 Hz response (Lins *et al.,* 1995) but this research was done on children.

6.2.5 SUMMARY OF FINDINGS (PHASE 1)

- ASSR threshold estimates were found to be sufficiently accurate to predict pure-tone thresholds;
- ASSR thresholds and pure-tone thresholds correlated to within 10 dB;
- ASSR thresholds prediction value was the poorest at 500 Hz;
- ASSR thresholds favoured abnormal hearing;
- 10 dB decrements, as a threshold estimation technique, was sufficient to predict pure-tone thresholds accurately;
- ASSR methods were objective;
- ASSR methods were accurate in an adult population with sensory neural (noise-induced hearing loss);
- subject related factors such as movement, coughing and fidgeting influenced the quality of ASSR recordings;
- the fact that the audiologist is seated in an adjacent room during testing, makes it difficult to observe patient behaviour and thus precluded control over potential sources of error;
- SF- and MF- methods were not significantly different in their accuracy to estimate pure-tone thresholds but the SF-method were more time efficient;
- there were no significant effect from sedation on the sensitivity or test time of all ASSRs; and
- thus there is no motivation to use sedation if a patient co-operates.

With these results obtained the experimental research could thus now be focused on unco-operative subjects

6.3 UNCO-OPERATIVE MINE WORKERS (PHASE TWO)

6.3.1 TO DETERMINE WHETHER PURE-TONE THRESHOLD ESTIMATES CAN BE OBTAINED FOR UNCO-OPERATIVE WORKERS

6.3.1.1 Introduction

After proving that ASSR methods could accurately estimate pure-tone thresholds in an adult mine worker population with noise-induced hearing loss and after the most efficient modulation frequency and stimulation technique had been decided on, the experimental research could be advanced to the final phase, in which the clinical value of these methods could be tested in an unco-operative sample of mine workers.

6.3.1.2 Revision of Phase 1 procedures: Implications for Phase 2

The 29 subjects in the unco-operative group (Phase 2) were tested using ASSR methods, in particularly the SF-technique with a modulation rate of 40 Hz. Although the findings in the first phase with co-operative subjects had indicated that sedation did not improve sensitivity or reduce test times for co-operative subjects (as reflected in Tables 6.12 and 6.13), common experience with pseudohypacusic workers, who may be motivated by the prospects of noise-induced hearing loss compensation, led to a decision to use sedation for the unco-operative group. A second variation in the procedures from those used for the phase one subjects was the use of a single room for both the subject and the audiologist, to allow control over body movement and other sources of noise from subjects.

6.3.1.3 Results obtained

The results of the pseudohypacusic groups' diagnostic- and ASSR test are set out in Appendix O. The ASSR and pure-tone thresholds of the 29 subjects differed on average from each other by 61, 08 dB. This is in contrast to the less than 10 dB difference with co-operative subjects. The ASSR results have conclusively proven that the pseudohypacusic group's diagnosis was

accurate. This diagnosis was made where there was a discrepancy larger than 15 dB between the same frequency's thresholds during two tests.

Table 6.13 indicates the deductions that were made from the results of the pseudohypacusic group.

TABLE 6.14: DEDUCTIONS MADE FROM THE ASSR THRESHOLDS OBTAINED IN PSEUDOHYPACUSIC WORKERS

PERCENTAGE OF CASES CONCLUDED	ABNORMAL HEARING (>25 dB PTA)	COMPENSABLE LOSS (RMA guidelines)	UNFIT	POOR CORRELATION WITH PRE-VIOUS TESTS	SUDDEN HEARING LOSS
96,5%	82,8%	48%	20,7%	48,3%	31%

Of the 29 pseudohypacusic subjects, 96,5 per cent could be successfully diagnosed and the cases could be concluded on the basis of the ASSR results (Table 6.14 and Appendix O). In only one case of the 29 (subject 2, Appendix O) did ASSR testing fail to estimate hearing thresholds, and this was in one ear only, due to excessive electrical activity that was unrelated to the subject's hearing. These results provide overwhelming support for the use of ASSR testing as a valid method to determine hearing thresholds for pseudohypacusic mine workers with noise-induced hearing loss.

It was also found that 10, 3 per cent of the left ears and 17,2 per cent of the right ears of the pseudohypacusic subjects tested had normal hearing (Table 6.14 shows abnormal hearing of 82,2 per cent). (See Appendix O as well). This is an important and logical finding when it is taken into consideration that as mine workers these subjects had been exposed to hazardous noise for considerable periods (with a mean of 20 years). Audiologists assessing such patients must be aware of the strong likelihood that pseudohypacusic individuals will be hearing-impaired, and failure to conclude a diagnosis may

have moral as well as health and safety implications in such cases. Although 82, 8 per cent of the subjects had abnormal hearing, only 48,3 per cent were compensable according to South African standards (see Table 6.14 and Appendix O), indicating that the determination of all the thresholds necessary (through the use of ASSRs) makes differential diagnosis possible, such as in cases of unilateral hearing loss which is not attributable to noise exposure.

Of the pseudohypacusic subjects, 20,7 per cent were found to be unfit for their present duties (Table 6.14 and Appendix O), based on current guidelines (Geyser, 2003). If audiologists fail to adequately assess worker fitness, as can easily occur with conventional screening and diagnostic procedures, the employer and workers are subject to greater safety risks, and there is likely to be a negative impact on productivity. In this respect, accurate once-off threshold estimation using ASSR methods would be beneficial.

Less than half (48,3 per cent) (Appendix O) of the ASSR thresholds correlated well with previous screening results, which is cause for some concern. In dealing with pseudohypacusic patients, audiologists are compelled to make recommendations based largely on previous screening results where this is the only source of additional information. The present finding indicates that previous screening results may be an unreliable indicator of hearing status for more than half of pseudohypacusic workers, possibly because workers have been manipulating their test results over several years. However, a more worrying possibility is that of a sudden deterioration in hearing, that may be present which will invariably progress to compensable levels. In examining subjects' previous screening results, it was found that 31,0 per cent (Appendix O) showed signs of sudden deterioration not attributable to noise exposure and warranting further medical investigation. (This was possible by studying previous screening results).

6.3.1.4 Time required for ASSR testing

After an average time of 8,1 minutes for skin cleaning/preparation and the placement of electrodes, an average of 49.86 minutes was required for the

ASSR recordings in the pseudohypacusic group (Appendix O). This compares very well with the 51.56 minutes (Table 6.7) required to obtain 10 thresholds (5 test frequencies per ear) in the co-operative group (Phase 1). This indicates that one hour would be needed for each ASSR test. This makes it a lengthy procedure in comparison to conventional methods, but it provides more essential information.

In comparing these test times with those for co-operative subjects (Phase 1) it does not appear that the use of a single room for the audiologist and the subjects (as opposed to a separate test booth in Phase 1) made any appreciable difference to the test time. It is also possible that the testing time was very similar due to the fact that the audiologists' presence inhibited negative behaviour from pseudohypacusic subjects. Nevertheless, it is recommended that a single room be used, to discourage deliberate movement and other sources of noise from unco-operative patients.

6.3.1.5 Summary of Phase 2

- ASSR testing confirmed the diagnosis of pseudohypacusis;
- in 96,5 per cent of cases with pseudohypacusis could diagnostic procedures be completed;
- 82,8 per cent of pseudohypacusic subjects had abnormal hearing;
- 48 per cent of abnormal cases were compensable;
- 20,7 per cent of cases were unfit for their current duties;
- in 48,3 per cent of pseudohypacusic cases did ASSR thresholds show poor correlation with previous screening tests;
- there were evidence of sudden hearing deterioration in 31 per cent of pseudohypacusic cases;
- ASSR testing makes differential diagnosis possible;
- previous screening results were not a good indicator of present hearing status
- the time needed for ASSR testing in Phase 2 was very similar to the time required for the co-operative group;

- an hour is sufficient time for ASSR testing if skin preparation procedures is also taken into consideration; and
- it is recommended that a single room set up is followed when testing pseudohypacusic workers.

6.4 RESEARCH RESULTS REALISING THE PRINCIPAL AIM OF THE STUDY

The principal aim of the present research was to determine whether ASSR testing could successfully conclude audiological assessment procedures for pseudohypacusic mine workers. The question that had to be addressed was: **Is there clinical value in using this AEP technique with mine workers with noise-induced hearing loss and more specifically these with pseudohypacusis?**

The inability of conventional procedures to provide accurate thresholds for difficult-to-test individuals who are often unco-operative, commonly leads to a repetition of screening and diagnostic procedures and referral to an Ear-, Nose- and Throat specialist in an effort to resolve possible compensation cases. Very often, ABR testing is recommended. This test provides limited threshold information in the 2000 to 4000 Hz frequency range, but otherwise only confirms the presence of pseudohypacusis without determining the thresholds needed for a compensation claim or for fitness-for-work evaluations. In some instances this leaves deserving claims unresolved, while in others it results in overcompensation due to deliberately exaggerated hearing loss.

Through the current study it has been conclusively proven that ASSR methods have sufficient clinical value in a mine worker population with sensory neural hearing loss (noise-induced hearing loss). Even in a sample of unco-operative workers this auditory evoked potential managed to assist in concluding the diagnostic procedures. The clinical value lies in the fact that it is an accurate and reliable alternative to pure-tone methods for determining thresholds in adult mine workers. It can furthermore serve as a single test in a

battery if co-operation is withheld. The time requirements are certainly reasonable in the field of AEPs.

Further clinical value is also derived from the fact that the use of ASSRs in a pseudohypacusic population with noise-induced could conclude audiological procedures and lead to correct recommendations re compensability, differential diagnosis and amplification. Roeser *et al.* (2000b) alert to the fact that the identification of pseudohypacusis is extremely important to ensure that the patient receives appropriate intervention but also to avoid harmful intervention. The fact that the overwhelming majority of pseudohypacusic workers had hearing loss shows the danger of only rescheduling pseudohypacusic workers for annual testing if thresholds could not be obtained.

An important finding that should be considered by audiologists is the fact that previous screening tests were not a good indicator to use as a basis for recommendations if hearing thresholds cannot be obtained. Very often this is all an audiologist has if a patient withholds co-operation.

Much clinical value is derived from the fact that ASSRs are an objective procedure. The audiologist as well as the patient does not influence the results. Definitely an important finding in a population that is traditionally unco-operative.

Roeser *et al.* (2000b:12) define the effectiveness of audiological tests as follows:

> All diagnostic procedures, whether for the auditory system or any other system, are designed to identify the presence of a disorder as early as possible. When indicated, diagnostic procedures can also help to identify the cause or nature of the disorder. The value of a diagnostic test depends on the ability to perform as intended. That is, the procedure must accurately identify those patients with the disorder while clearing those patients without the disorder.

In summary ASSRs have performed as intended.

6.5 SUMMARY

The results of the experimental research were presented in Tables, Figures and Appendices. The results were discussed and correlated with the current literature in the field of ASSRs and pseudohypacusis and conclusions were finally drawn.

The clinical value of ASSR testing in mine workers with noise-induced hearing loss and pseudohypacusis have thoroughly been researched, tested and evaluated and found to be a reliable alternative to pure-tone testing.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

AIM

To integrate the findings of the study and to critically evaluate the results of this study against the theoretical framework supplied in Chapters 1 to 4. The value of this study is discussed in terms of the application of auditory steady state response testing in the mining industry in general and in the testing of workers with pseudohypacusis in particular.

7.1 INTRODUCTION

Mine workers who have noise-induced hearing loss and believe that they may qualify for financial compensation may be unco-operative patients. This lack of co-operation during audiological assessments leads to an inability on the side of audiologists to establish reliable pure-tone hearing thresholds. If feigning of hearing loss or the exaggeration of an existing hearing loss is not identified by the clinician it is logical to conclude that the financial impact on employers originating from fallacious claims and overcompensation is considerable. If on the other hand the pseudohypacusis is identified but not quantified, the number of pending cases is likely to escalate, thus impeding efforts to finalise genuine claims for noise-induced hearing loss. It has been the experience in the clinical situation that in many instances follow-up assessment procedures also fail to provide the accurate hearing thresholds needed to finalise a claim, putting the clinicians in a position of having to make debatable recommendations with regard to rehabilitation, fitness for work and compensation.

One or all of the following complications can follow from the clinical problem of pseudohypacusis in the mining industry (De Koker, 2003):

- frustration is experienced on the part of audiologists and occupational health personnel. There develops a mistrust on the part of workers, with retesting and counselling failing to make a difference in eliciting their co-operation (Franz, 2003);
- escalating costs for audiological assessments, often without a successful diagnosis other than confirmation of pseudohypacusis (De Koker, 2003);
- greater number of specialist referrals is generated due to the failure of current audiological procedures to finalise cases, including many that have been referred previously and remain inconclusive due to a lack of patient co-operation (Geyser, 2003);
- claims from workers who genuinely deserve to be compensated, but that are not settled due to the absence of reliable hearing thresholds;
- the compensation of workers with normal hearing;
- further exposure of workers with severe hearing loss who should have been declared unfit for work in noisy areas, to the detriment of their remaining hearing and quality of life, as well as to their safety and that of their fellow workers (De Koker, 2003);
- the overlooking or misdiagnosis of cases of a sudden onset of hearing loss and ear pathology due to the audiologist's inability to obtain hearing thresholds in unco-operative clients; and
- the impossibility to make a differential diagnosis without reliable pure-tone thresholds (Roeser *et al*., 2000b).

It is clear that above stated problem of pseudohypacusic mine workers exaggerating and feigning hearing loss makes the audiological assessment of these workers problematic as can be seen in the above description. This is however a responsibility that cannot be disregarded as Roeser *et al.* (2000b) said. "Today audiologists are the primary health care professional involved in the identification, prevention, and evaluation of auditory and related disorders". The responsibility therefore also lies with the audiologist to find a solution to the time

consuming and costly problem. An audiologist needs to find a solution in the interest of audiology as a profession, the individual worker, the insurance companies and mine management.

A possible solution to the problem of pseudohypacusis was addressed in this research project by studying pseudohypacusis as a phenomenon and by researching the previous audiological solutions in difficult-to-test populations. A literature review of auditory evoked potential procedures, the most common solution in unco-operative patients, has lead to the possibility that a new auditory evoked potential could bring a solution to the described problem. ASSRs, an objective evoked potential was researched and experimented with.

The question asked was: **Is there an audiological technique available that cannot only identify pseudohypacusis but, more importantly, estimate the true behavioural thresholds of pseudohypacusic mine workers with noise-induced hearing loss?** In the definition (and realisation) of the aim of the study there was emphasis placed on what the clinical value of ASSR testing would be in the described population.

Clinical value was defined as the accuracy in predicting or estimating thresholds and the time-effectiveness in assessing noise-induced hearing loss in pseudohypacusic workers. The results of the empirical parts of this study have been presented in the previous chapter. However it is necessary to conclude the study by interpreting, evaluating and summarising the findings. Offering recommendations for further research logically emerge from such an evaluation. This final chapter concludes by suggesting the way forward.

7.2 RESEARCH FINDINGS

The findings of the present study, considering all the sub-aims (Phase 1) where different ASSR procedures were evaluated, can be summarised as follows:

7.2.1 CONCLUSIONS BASED ON THE RESULTS FROM CO-OPERATIVE MINE WORKERS WITH NOISE-INDUCED HEARING LOSS

The most important result was that all procedures were within 10 dB of the pure-tone threshold. From this it can be concluded that:

- ASSRs (all procedures) offer an accurate alternative to behavioural methods for determining/estimating pure-tone thresholds for adult mine workers with noise-induced hearing loss, a type of sensory neural hearing loss (ASSR and pure-tone thresholds within 10 dB from each other);
- ASSRs offer accurate threshold estimates across the range from normal to severe sensory neural hearing loss however ASSRs were found to favour pathological ears;
- The biggest difference between pure-tone and ASSR thresholds were found at lower frequencies as is the case in other research (500 Hz: 8,20 dB in the right ears) (Lins *et al*., 1996 and Schmulian, 2002);
- 10 dB intervals (decrements and increments) used in ASSR threshold estimation did supply accurate estimates of pure-tone thresholds. It can be concluded that it will thus not be necessary to lengthen an already long procedure by using 5 dB intervals;
- The Audera testing system (SF- and monotic) enabled an objective test procedure that could not be manipulated by the clinician or the subject;
- The SF-monotic technique was found to be more time-efficient than the MF- method (51,56 minutes versus 84,14 minutes), and also yielded more accurate threshold estimates at 500 Hz. (right-ear SF=8,39 (mean): MF=16,66 (mean); p=0,0014);
- In comparing the modulation rates it was found that the 80 to 110 Hz was 33 minutes longer than the average test time for the 40 Hz procedure. It seems to be clear that the 40 Hz rate is more time-efficient when applied to adults with sensory neural hearing loss;

- Sedation did not improve the sensitivity or reduce it, nor reduce the test time for the SF- or MF-methods and thus is there no motivation for using sedation if passive co-operation can be obtained from the patient;
- ASSR results were, as was found in other research, not influenced by the age of the subjects (Stapells *et al*., 1984; Rane *et al.*, 1995);
- Subject related factors such as movement, coughing and fidgeting seem to influence the quality of the ASSR recordings as found by Aoyagi *et al*., (1994) as well. This behaviour needs to be prevented, especially if there is an intention on the side of the patient to confound results. A single room set-up, where the audiologist is seated in the testing room with the patient, offers a solution to this possibility.

7.2.2 CONCLUSIONS BASED ON RESULTS WITH PSEUDOHYPACUSIC MINE WORKERS

These findings for the co-operative group of 81 subjects with noise-induced hearing loss indicated that the principal aim of the study could be addressed next, in other words to determine the clinical value of ASSR methods for evaluating pseudohypacusic mine workers with noise-induced hearing loss:

- ASSR tests confirmed the diagnosis of pseudohypacusis;
- It has been found that the use of ASSRs in a pseudohypacusic population with noise-induced hearing loss could conclude audiological procedures (in 96,5 per cent of cases) and lead to correct recommendations with regard to compensability, differential diagnosis and amplification;
- The overwhelming majority (82, 8 per cent) of pseudohypacusic workers had some hearing loss. It is thus important for audiologists not to keep on re-scheduling workers with hearing loss without correct recommendations with regard to specialist referrals and rehabilitation;
- The majority (82,8 per cent) of the pseudohypacusic patients had hearing loss but only 48,3 per cent were compensable. From this observation it is

clear that ASSR testing made differential diagnosis possible and it is thus incorrect to assume that all workers with hearing loss are compensation candidates due to the fact that they work in noise;

- The use of ASSRs made it clear that 20,7 per cent of the workers in the pseudohypacusic sample were unfit for their work. The inability to diagnose the organic component in pseudohypacusis thus does cause workers to work in conditions detrimental to their health and safety;
- Less than half (48,3 per cent) of the ASSR thresholds correlated well with the results of previous screening tests. This is a worrying finding since very often previous results are all that an audiologist has to base recommendations on. A possible explanation of this phenomenon is that pseudohypacusic behaviour might have been present for a number of years but more serious that there might have been a sudden deterioration of hearing which leads to the following finding that;
- Disturbingly 30,1 per cent of the pseudohypacusic subjects have experienced a sudden deterioration in hearing if one studies their previous thresholds. Due to the possible serious nature of sudden hearing loss audiologists are obliged to make the diagnosis;
- The ASSR procedure has proven to be lengthy in comparison to conventional testing (approximately 60 minutes including preparation time, compared with the 17 minutes typically required for pure-tone audiometry, an otoscopic examination and immittance measurements). It is nevertheless advantageous if it is considered that the 17 minutes is not standard in the case of pseudohypacusis and how many times pseudohypacusic workers need repetitive testing;

To summarise: the findings indicate scientific support for the use of ASSR methods as a more reliable alternative to pure-tone testing of adults with noise-induced hearing loss, and that ASSRs can serve as a once-off procedure to conclude the diagnosis of pseudohypacusis and make the correct handling of the

case possible. ASSR results met the requirements for accurate threshold estimates at all the frequencies required for compensation and fitness-for-work evaluations.

7.3 CRITICAL EVALUATION OF THE RESEARCH

7.3.1 RELIABLE ALTERNATIVE TO PURE-TONE METHODS

The norm adopted in this study of a reliable difference between two different hearing tests of 10 dB (RMA guidelines, 2003) is audiometrically acceptable. The threshold seeking procedure of 10 dB threshold bracketing (Picton *et al.,* 2003) used in this study can probably be improved when one uses 5 dB intervals which is possible with the equipment used in this study. Nevertheless the study has shown that ASSRs can be used as an alternative to pure-tone testing in adults with hearing loss.

Furthermore, the reliability of the use of ASSR thresholds is enhanced by a positive critique on this study namely the number of subjects used (in Phase 1 a sample of 81 was used). Picton *et al.* (2003) summarised studies (done up to 2003) that used the 40 Hz response (11 studies) and indicated that the number of subjects used in these studies varied between six and 40 per study.

It can be seen as a limitation of the present study that no indication of inter-test repeatability was provided, because the need to avoid interference with production schedules precluded any repetition of the lengthy testing procedures by a second clinician. It was also not possible to compare the same subjects' performance on different ASSR protocols due to the same time constraint. These limitations may well have influenced the results, or more probably the generalisation of the results.

7.3.2 THRESHOLD ESTIMATES ACROSS THE SEVERITY RANGE

ASSR testing proved to be accurate in estimating hearing thresholds that ranged from normal to profound. Picton *et al*. (2003) cite 22 studies done with ASSR methods. Only six of these studies used a sample of primarily hearing impaired subjects. The present study thus adds to the limited research on ASSR testing applied to hearing impaired subjects. Furthermore, since the subjects had noise-induced hearing loss, a specific type of sensory neural hearing loss, it is possible that these results could be generalised to adults with sensory neural hearing loss derived from other types of etiology.

It was also concluded that the lack of algorithms for sloping sensory neural hearing loss in the multiple dichotic stimulation was a negative factor that needs to be addressed.

7.3.3 FEWER ASSR THRESHOLDS OBTAINED IN COMPARISON WITH PURE-TONE THRESHOLDS

The influence of patient-generated noise on electrophysiological techniques is an ongoing clinical concern (Abramovich, 1990; Ferraro & Durrant, 1994). Artefacts from high levels of background EEG activity can lengthen ASSR procedures and there is a lack of standardisation for the testing environment, patient instructions and permissible level and number of artefacts. These should be specified on the basis of current knowledge and they should be published, to enable inter-study comparisons and a further refinement of ASSR techniques. In the case of an unco-operative client it is recommend that the clinician be placed in the same room as the subject to prevent deliberate movement and coughing. Sedation might also still be needed in a subject who refuses to co-operate.

Apart from the electrophysiological noises influencing threshold estimation, one needs to ask whether limitations of the equipment used also impeded the study. Multiple-frequency methods would not be practical in the mining industry, since

only eight out of the ten thresholds required can be covered in a single test run. That means that a MF-technique must be repeated to get all the required thresholds and thereby a lengthy procedure is prolonged even further.

Finally, in the planning of the research it was deemed important to select equipment that can test all the frequencies specified by current South African legislation. The Audera equipment that was available during the initial phases of the experimental research could not test 3 000 Hz which is problematic since this frequency is legally required (Workmen's Compensation, 1995).

It is thus invisaged that as equipment improve in reaction to further research that ASSR method will gain acceptance into standard audiological procedures. In the words of *Roeser et al.* (2000b:p10):

> Auditory evoked responses have been used in diagnostic audiology for more than 3 decades, and as more knowledge is being made available in this area, it is clear that auditory electrophysiological measures will become an even more prominent tool in audiology in future.

7.3.4 THE DIFFERENCE BETWEEN ASSR AND PURE-TONE THRESHOLDS AT 500 HZ

The ASSR test has, as was the case with other researchers, proven to be less accurate at 500 Hz (Rickards *et al.*, 1994). It is important for clinicians to remember this fact when testing patients and to be aware that using 5 dB increments and decrements in testing might improve the threshold estimates' accuracy.

Clinicians should also do everything in their power to limit background noise since background noise can influence threshold estimates at 500 Hz. The most

important requirement is certainly to test subjects in a calibrated sound proof environment.

7.3.5 INTERVALS OF TEN dB IN ASSR THRESHOLD ESTIMATION

In the above paragraph it was mentioned that 5 dB increments could improve the accuracy of ASSR techniques. It must nevertheless be remembered that 10 dB threshold estimation techniques were proven to supply threshold estimates that were within the required 10 dB variance. This finding gives a clinician the freedom to assess a clinical situation and to choose the decrements accordingly depending on the time constraints and the patient's needs.

7.3.6 THE AUDERA SYSTEM

The fact that the Audera system (Biologic Systems Corporation, 2002) had a test procedure in place where the number of sweeps and averages were controlled by computer algorithms made the use of this equipment more objective (neither the audiologist nor the patient do decide on the results). It is very important that ASSR testing should be an objective procedure, particularly where clinicians may be inexperienced and in working with a population where thresholds are used to calculate the compensation to be paid out. It is understandable that the more objective and accurate these thresholds are, the less chance there is of distributing the available monetary resources incorrectly. This objectivity is also a very important finding in a population that is traditionally unco-operative.

A problem with the Biologic system was that the clinician could select how many averages and sweeps to use (which is obviously important in research settings). In this specified population these parameters should be held constant at the researched best parameters in order to ensure objectivity and to be able to compare different research endeavours.

7.3.7 THE SF-MONOTIC TECHNIQUE

The conclusion is that SF-ASSR procedures proved to be the method of choice for pseudohypacusic patients with noise-induced hearing loss, due to the robustness of the 40 Hz response and the fact that the procedure eliminated any need to expose subjects to high-intensity stimulation at the low test frequencies. In conjunction with this, it was also found that the SF-testing also provided for manual control of the stimulus intensity, allowing the intensity level to be adjusted where a response could not be obtained, as with conventional pure-tone tests. The SF-technique could thus prevent high intensity stimulation in high frequencies from influencing the thresholds at other frequencies. This was not possible with the MF-procedure (Picton, *et al.,* 2003).

7.3.8 THE 40 Hz MODULATION

Since most of the members of difficult-to-test populations are usually infants, there has there been a tendency for researchers to move away from the 40 Hz response (Rance *et al*., 1995; Herdman & Stapells, 2001; John *et al.*, 2002). However, the present research seems to indicate that this stimulation rate was still the best to use in an adult population and thus confirms the opinion of Galambos *et al*. (1981) and Dobie and Wilson (1998) in this regard.

7.3.9 SEDATION

The fact that sedation did not improve or have a negative effect on the sensitivity or reduce the test time of ASSR methods leads to the conclusion that there is limited justification using it when passive co-operation can be obtained from a patient. This was a welcome result, in view of the ethical and medical constraints with regard to the use of sedation.

On the other hand particularly in the case of pseudohypacusic mine workers from whom passive co-operation cannot be obtained, it is reassuring that sedation has

been seen not to affect the ASSR thresholds and time negatively and thus sedation can still be used if electrophysiological noise is found to affect the results.

7.3.10 CONCLUSION OF AUDIOLOGICAL PROCEDURES

It has previously been shown that there is a very high incidence of pseudohypacusis in the South African mining industry (De Koker, 2003). The lack of cooperation from workers leads to a high case load of unresolved cases. The fact that these cases could have been diagnosed and completed with the use of ASSR methods leads one to conclude that it would be unethical not to use this tool available to audiologists to resolve pending cases. The audiologist, as a professional, is obliged to give an accountable service.

The one unconcluded case in the present study (one ear) was due to electrophysiological noise and therefore the limiting of factors influencing the data is an ongoing clinical and research concern.

7.3.11 PSEUDOHYPACUSIC WORKERS HAD HEARING LOSS

In the past it was common practice that pseudohypacusic workers would be counselled and re-tested at a later date. The fact that such a high percentage of pseudohypacusic workers tested had a true basic hearing loss emphasises the need to raise the awareness with audiologists that it is not acceptable to reschedule a population with pathology for numerous tests over many years without diagnosing the degree and cause of the hearing loss (Roeser *et al.,* 2000b) and without making the correct recommendations with regard to amplification, fitness and compensability (De Koker, 2003).

7.3.12 PSEUDOHYPACUSIC WORKERS WITH HEARING LOSS WERE NOT NECESSARILY COMPENSABLE

In the mining industry workers are mainly referred since their hearing loss is potentially compensable. This leads to a specific focus from the side of the audiologists and other health workers in this sector that is problematic and should change. This study has proven that less than half of the pseudohypacusic workers with hearing loss were compensable. However one can only conclude that ethical audiologists should remember their role in differential diagnosis (Roeser *et al.,* 2000b) and that this population, like any other population, also suffers from other types of hearing loss (not only noise-induced). Certainly pseudohypacusic workers do form part of the client base of audiologists and deserves the best the profession of audiology can offer.

7.3.13 UNFITNESS OF PSEUDOHYPACUSIC WORKERS

In the past the fact that pseudohypacusic cases stayed pending led to the possibility that workers unfit for duty could pose a risk to fellow workers due to their unability to hear danger signals. An unfortunate worker with serious noise-induced hearing loss could also have been exposed indefinitely due to the fact that accurate hearing thresholds were outstanding. This possibility can be eliminated by the use of ASSR techniques.

7.3.14 ASSR THRESHOLDS DID NOT CORRELATE WELL WITH PREVIOUS SCREENING TESTS

In the past the only tools the audiologist had to resolve a long-standing pending case was to do an ABR test or to study previous screening tests. If an ABR could not be done due to monetary constraints, the previous screening tests were the only guideline to base recommendations on. This study has shown the danger of rescheduling pseudohypacusic workers for annual testing if thresholds could not be obtained. It has also been proven that previous screening tests were not a good indicator to use as a basis for recommendations if hearing

thresholds were outstanding. It is thus concluded that every effort should be made to resolve and diagnose pending cases.

7.3.15 PREVALENCE OF SUDDEN HEARING LOSS

A worrying finding was that there was evidence that 30,1 per cent of the pseudohypacusic subjects have experienced a sudden deterioration in hearing. This deterioration would not have been diagnosed without determining or estimating the true pure-tone thresholds. Again the importance of resolving outstanding cases is highlighted with this finding.

7.3.16 ASSR-AN IMPORTANT CONTRIBUTION TO THE MINING INDUSTRY

ASSR methods are more costly than conventional pure-tone tests, but ASSRs can save the mining industry a lot in terms of cost of lost production, transport, referrals and overcompensation. The well-being of the individual worker and his co-workers are promoted in that deserving compensation cases are diagnosed, sudden deterioration in hearing is identified and a worker is notified when he is not fit to work in a noisy environment any longer. ASSR tests can also limit the financial impact of overcompensation and unresolved claims.

Based on the theoretical and empirical results of this study an additional situation analysis pertaining to the financial implications of ASSR methods was executed. The specific details are set out in Appendix Q, but the most important results are:

- It is impossible to know how much pseudohypacusis has cost the industry (Begley, 2003) but it can be unequivocally stated that pseudohypacusis has got financial implications due to lost production and shifts, transport costs, specialist referrals and overcompensation. It is thought to be substantial;

- On information received it was found that an ASSR system can at present cost as much as R154 000,00 (HASS, December, 2003). ASSR systems are thus more expensive than conventional audiometrical equipment;
- However, when comparing costs of overcompensation, transport arrangements, specialist referrals, numerous hearing tests and lost production it is clear that ASSR testing will save the industry.

7.3.17 LENGTHY PROCEDURE

The procedure has proven to be a lengthy one in comparison to conventional testing (approximately 60 minutes including preparation time, compared with the 17 minutes typically required for pure-tone audiometry, otoscopic examination and immittance measurements). In the field of auditory evoked potentials it is nevertheless an acceptable time frame. The length of the procedure is a negative point to consider with the general high case loads found in the mining industry. It must nevertheless be remembered that numerous testing of pseudohypacusic workers with conventional tests are also time consuming.

7.4 LIMITATIONS OF THE RESEARCH

The following limitations were experienced in the current research and it is recommended that these issues be addressed in forthcoming research:

- The MF-ASSR (dichotic) procedure had no algorithms (at this point in time) to compensate for the greater hearing thresholds at higher frequencies typical of sensory neural hearing loss. This lead to the fact that the lower frequencies' thresholds were influenced by the high intensity high frequency stimulation.
- Standards are required for the number of sweeps and averages needed to ensure accuracy. In a clinical situation the extent of averaging should be determined by appropriately formulated algorithms and not by the clinician,

to ensure objectivity. The lack of standardisation makes it difficult to compare studies. In the present study, the amount of averaging was controlled in the SF-method but was left to the clinician's discretion in the MF- procedure.

- In selecting experimental subjects with noise-induced hearing loss, it was stated that subjects had sensory neural hearing loss. The "neural" aspect was not investigated to determine, for example any influence of retro-cochlear damage. It has recently been proven that patients with Human Immunodeficiency Virus (HIV) do experience retro-cochlear deterioration (Chandrasekhar *et al.,* 2000). As this condition is currently an African pandemic it is reasonable to recommend that a clinical study be done using ASSR methods in combination with click ABR testing, to allow differential diagnoses which are not possible with ASSRs alone.
- The present study makes no mention of the possible influence of the HIV on the study results. HIV, the causative agent of Acquired Immunodeficiency Syndrome (AIDS), is associated with the development of opportunistic infections and central nervous system disorders known to induce hearing impairment. In addition, a large percentage of patients in the mining industry are also treated with various combinations of ototoxic drugs for the treatment of tuberculosis and HIV-related manifestations. This points to a need for an investigation of the contribution of HIV to hearing problems among mine workers and how a differential diagnosis of multi-factor hearing loss can be made. Since all evoked responses, including ABRs, are highly dependent on the temporal synchronisation of neural activity, it is reasonable to expect alterations in ABR and ASSRs among patients with varying degrees of HIV infection. The preceding point raises the question of the extent to which noise-induced hearing loss compensation is affected by audiological changes due to HIV infection or its complications.

- The present study did not evaluate the accuracy of late cortical evoked responses (CER) in estimating hearing thresholds for pseudohypacusic patients. This procedure has been used in Australia for more than 20 years (Rickards and De Vidi, 1995) but at the time of the research, equipment was not readily available in South Africa. Apart from the unavailability of the equipment did the skill and knowledge required of the clinician in executing CER methods discourage the researcher. However future investigations could well be directed at evaluating this method of audiological assessment.

7.5 THE STUDY IN CONTEXT

In conclusion, ASSR testing offers an objective and accurate means of determining hearing thresholds for pseudohypacusic mine workers. ASSR testing also offers the option of the use of complex stimuli for threshold estimation, thereby stimulating the auditory system in a manner that is more representative of the way in which the hearing sense functions, in comparison to, for instance pure-tone clicks and tone bursts (Picton *et al.,* 2003).

With this study a contribution was made to the field of Audiology in that limited clinical validation of ASSR methods has been extended. This procedure had not previously been tested on mine workers with noise-induced hearing loss and no other study could be found where ASSRs had been used in a pseudohypacusic population. The present research has also made a contribution to the scientific body of knowledge in the South African mining industry and has contributed to the setting of international standards in audiological assessments in the industry. Current research can now be implemented in the industry and a contribution has been made to a best practice procedure for evaluating noise-induced hearing loss.

"As expected, in the 50 years the profession of audiology has been in existence the scope of practice has grown. This metamorphosis has occurred gradually as a result of emerging clinical, technological, and scientific developments, which are now commonplace in our modern world. Whereas only 25 years ago audiologists were primarily performing behavioural tests of auditory function, today the typical audiologist has a wide range of electrophysiological assessment tool to select from" (Roeser *et al.,* 2000b: p1).

The audiologist should use these tools in the interest of the patient, the client and the profession and in a wider sense also in the interest of South Africa as a whole.

BIBLIOGRAPHY

Abramovich, S. 1990. E*lectric response audiometry in clinical practice.* New York: Churchill Livingston.

Aoyagi, M., Kiren, T., Furuse, H., Fuse, T., Suzuki, Y., Yokota, M. & Koike, Y. 1994. Pure-tone threshold prediction by 80Hz amplitude-modulation following response. *Acta Oto-laryngologica,* 511:7-14.

Aoyagi, M., Suzuki, Y., Yokota, M., Furuse, H., Watanabe, T. & Ito,T. 1999. Reliability of 80Hz amplitude modulation following response detected by phase coherence. *Audiology and Neuro-otology,* 4:28-37.

Aoyagi, M., Yamazaki, Y., Yokota, M., Fuse, T., Suzuki, Y., Itoh, S. & Watanabe, T. 1996. Frequency specificity of 80Hz amplitude-modulation following response. *Acta Oto-laryngologica,* 522:6-10.

Arnold, S.A. 2000. *The auditory brainstem response.* In J. Roeser, M. Valente & H. Hosford-Dunn (Eds.), *Auditory diagnosis* (pp. 451-470). New York: Thieme Medical Publishers.

Barber, C. (Ed.). 1980. *Evoked potentials.* Lancaster: MTP Press.

Barber, C. & Taylor, M.J. (Eds.). 1991. *Evoked potentials review, No 4.* Nottingham: IEPS Publications.

Belco, J. 2001. *AAA – 13th Annual convention: Industrial Audiomety in Private Audiology practice: establishing an industrial hearing conservation division in a clinical practice and dispensing hearing aids.* San Diego.

Bankaitis, A.E. & Keith, R.W. 1995. Audiological changes associated with HIV infection. *ENT Journal,* 74: 53-359.

Barber, C & Blum, T. (Eds.). 1987. *Evoked potentials III.* Stoneham: Butterworths.

Barrs, D.M., Althoff, L.K., Krueger, W.W.O. & Olsson, J.E. 1994. Work-related, noise-induced hearing loss: evaluation including evoked potential audiometry. *Otolaryngology: Head and Neck Surgery,* No 110: 177-184.

Begley, A. 2001. abegley@randmutual.co.za, October. e-mail to E. de Koker (edekoker@webmail.co.za).

Begley, A. 2002. abegley@randmutual.co.za, November. e-mail to E. de Koker (edekoker@webmail.co.za).

Begley, A. (abegley@randmutual.co.za). (12 February 2003). Re: *NIHL.* E-mail to E. de Koker (edekoker@webmail.co.za)

Berg, B.L. 1998. *Qualitative research methods for the social sciences. (*3rd ed.). Boston: Allyn & Bacon.

Bess, F.H. & Humes, L. E. 1995. *Audiology: The fundamentals.* (2nd ed.). Baltimore: Williams & Wilkins.

Biologic personal communication. (ysaban@bisc.com) (28 October 2002) e-mail to E. deKoker (edekoker@webmail.co.za).

Bio-logic Systems Cooperation. 2002. *GSI Audera: User manual.* Madison, IL: Grason-Stadler.

Birchall, M.A., Wight, R.G., French, P.D., Cockbain, Z. & Smith, S.J.M. 1992. Auditory function in patients infected with the human immunodeficiency virus. *Clinical Otolaryngology,* 17:117-121.

Chaiklin J.B. & Ventry, I.M. 1965. Patient errors during spondee and pure-tone threshold measurement. *Journal of Audiological Research,* 5:219-230.

Chandrasekhar, S.S., Connelly, P.E., Brahmbhatt, S.S., Shah, C.S., Kloser, P.C. & Baredes, S. 2000. Otologic and audiologic evaluation of human immunodeficiency virus-infected patients. A*merican Journal of Otolaryngology,* 21(1):1-9.

Cohen, L.T., Rickards, F.W. & Clark, G. M. 1991. A comparison of steady-state evoked potentials to modulated tones in awake and sleeping humans. *Journal of the Acoustical Society of America,* 90:467-2479*.*

Coles, R.R.A. & Mason, S.M. 1984. The results of cortical electric response audiometry in medico-legal investigations. *British Journal of Audiology,* 18:71-78.

Compensation for Occupational Injuries and Diseases Act No.130 of 1993 (COIDA). Pretoria: Government Printer.

COMRO. 1988. *Guidelines for the implementation and control of a hearing conservation programme in the South African mining industry: User Guide no. 11*. Johannesburg:Chamber of Mines Research Organisation.

Dane, F.C. 1990*. Research methods*. Pacific Grove, CA: Brookes/Cole.

De Klerk, W. (william@netactive.co.za) (12 February 2003) Re: *Master.* E-mail to E. de Koker (edekoker@webmail.co.za).

De Koker, E. (edekoker@webmail.co.za) (28 October 2002) Re: *Questions regarding Biologic's MASTER.* E-Mail to Y. Saban (ysaban@blsc.com).

De Koker, E. 2003. Evaluate the viability of auditory steady-state response testing for pseudohypacusic workers in the South African mining industry. *Safety in Mines Research Advisory Committee: Project report: Health 020701*. Department of Minerals and Energy.

De Koker, E., Franz, M, Clark, A & Mackay, G. 2003. Feasibility of using oto-acoustic emission methods for screening early hearing impairment in South African mineworkers. *Safety in Mines Research Advisory Committee Project report: Health 802.* Department of Minerals and Energy.

De Vos, A.S. (Ed.). 2002. *Research at grass roots: For the social sciences and human service professions* (2nd ed.). Pretoria: Van Schaik.

De Waal, R. 2000**.** Objective prediction of pure-tone thresholds in normal and hearing impaired ears with distortion product otoacoustic emissions and artificial neural networks. Unpublished D.Phil tesis, University of Pretoria.

Dirks, D. 1973. Bone-conduction measurements. In J. Jerger (Ed.), *Modern developments in audiology* (2nd ed., pp. 1-32). New York; Academic Press.

Dimitrijevic, A., John, M.S., Van Roon, P. & Picton, T.W. 2001. Human auditory steady-state responses to tones independently modulated in both frequency and amplitude. *Ear & Hearing,* 22(2):100-111.

Dobie, R.A. 2001. Medical-legal evaluation of hearing loss. San Diego, CA. Singular.

Dobie, R.A. & Wilson, M.J. 1998. Low-level steady-state auditory evoked potentials: Effects of rate and sedation on detectability. *Journal of the Acoustical Society of America,* 104(6):482-488.

Doerfler, L.G. & Stewart, K. 1946. Malingering and psychogenic deafness. *Journal of Speech Disorders,* 11:181-186.

Dolphin, W.F. & Mountain, D.C. 1993. The envelope frequency following response (EFR) in the Mongolian gerbril to sinusiodally amplitude-modulated signals in the presence of simultaneously gated pure-tones. *Journal of the Acoustical Society of America,* 94:3315-3226.

ERA Systems (Pty) Ltd. 2000. *SSEP Based evoked response audiometer: User Guide.* Australia.

Ferraro, J.A. & Durrant, J.D. 1994. Auditory evoked potentials: overview and basic principles. In J. Katz (Ed.), *Handbook of clinical audiology* (4th ed., pp. 317-338.). London: Williams & Wilkins,

Frank, T. 1976. Yes-no test for non-organic hearing loss. *Archives of Otolaryngology,* 102:162-165.

Franz, M.R. & Phillips, J. I. 2001. Noise and vibration. In R. Guild *et al.* (Eds.), *A handbook on occupational health practice in the South African mining industry (*pp. 193-230). The Safety in Mines Research Advisory Committee.

Franz, M.R. 2003. Personal communication, CSIR, Johannesburg.

Fuzani, P.D. 1999. The type, degree and prevalence of hearing loss in HIV positive black female patients, at various clinical stages of infection in South Africa. Unpublished B Communication Pathology thesis, University of the Witwatersrand, Johannesburg.

Galambos, R. 1981. Tactile and auditory stimuli repeated at high rates 930-50), produce similar event-related potentials. *Ann NY Acad Sci*: 388:722-728.

Galambos, R. Makeig, S. & Talmachoff, P.J. 1981. A 40 Hz auditory potential recorded from the human scalp. *Proceedings of the National Academy of Sciences of the United States of America*, 78:2643-2647.

Gao, W., Ding, D., Zheng, Z., Raun, F. & Liu, Y. 1992. A comparison of changes in the stereocilia between temporary and permanent hearing losses in acoustic trauma. *Hearing Research,* 62:27-41.

Gelfand, S.A. & Silman, S. 1985. Functional hearing loss and its relationship to resolved hearing levels. *Ear & Hearing,* 6(3):151-158.

Geyser, J.. 2003, 10 March. Personal communication, General Practitioner, Randfontein.

Glasscock, M.E., Jackson, C.G. & Josey, A.F. 1987. *The ABR handbook: Auditory brainstem response.* New York: Thieme Medical Publishers.

Gold, S.T., Hunsaker, D.H. & Haseman, E.M. 1991. Pseudohypacusis in a military population. *ENT Technology*, 70(10):10 -712.

Goldstein, R. 1966. Pseudohypacusis. *Journal of Speech and Hearing Disorders,* 31:41-352.

Goldstein, R. & Aldrich, W.M. 1999. *Evoked potential audiometry: Fundamentals & applications.* Boston: Allyn & Bacon.

Gorga, M.P. 1999. Predicting auditory sensitivity from auditory brainstem response measurements. *Seminars in Hearing,* 20(1):29-43.

Grimaldi, L.M.E., Luzi, L., Martino, G.V., Furlan, R., Nemni, R., Antonelli, A., Canal, N. & Pozza, G. 1993. Bilateral eighth cranial nerve neuropathy in human immunodeficiency virus infection. *Journal of Neurology,* 240:363-366.

Hall, J.W. 1992. *Handbook of auditory evoked responses.* Boston: Allyn & Bacon.

Hall, J.W. & Chandler, D. 1994. Tympanometry. In J. Katz (Ed.), *Handbook of clinical audiology (*4th ed., pp. 283-299). London: Williams & Wilkins.

Hall, J.W. & Mueller, H.G. 1997. *Audiologists' desk reference (Vol. 1): Diagnostic audiology principles, procedures and practise.* San Diego, CA: Singular.

Hall, J.W. 2000. *Handbook of oto-acoustic emissions*. San Diego, CA. Singular.

Halliday, A.M. (Ed.). 1993. *Evoked potentials in clinical testing (*2nd ed.). New York: Churchill Livingstone.

Hanley, M. 1986. *Basic principles of auditory assessment.* San Diego, CA: College-Hill Press.

HASS Industrial (Pty) Ltd. 2003, December. Personal communication.

Haughton, P.M., Lewsley, A., Wilson, M. & Williams, R.G. 1979. A forced-choice procedure to detect feigned or exaggerated hearing loss. *British Journal of Audiology,* 13: 35-138.

Hausler, R., Vibert, D., Koralnik, I.J. & Hirschel, B. 1991. Neuro-otological manifestations in different stages of HIV infection. *Acta Oto-laryngologica,* 481:515-521.

Herdman, A.T. & Stapells, D.R. 2001. Thresholds determined using the monotic and dichotic multiple auditory steady-state response technique in normal-hearing subjects. *Scandinavian Audiology,* 30(1):1-49.

Hood, L.J. 1995. Estimating auditory function with auditory evoked potentials. *Hearing Journal,* 48(10):32-42.

Hood, L.J. 1998. *Clinical applications of the auditory brainstem response.* San Diego, CA: Singular.

Hyde, M., Matsumoto, N., Alberti, P. & Yao, L. 1986. Auditory evoked potentials in audiometric assessment of compensation and medicolegal patients. *Annals of Otology, Rhinology & Laryngology,* 95:514-519.

Jerger, J. 1960. Bekesy audiometry in analysis of auditory disorders. *Journal of Speech and Hearing Research,* 3:275-287.

Jerger, J.F., Grimes, A.M., Jacobson, G.P., Albright, K.A. & Moncrief, D. 2000. In R.J. Roeser, M. Valente & H. Hosford-Dunn (Eds.), *Audiology diagnosis* (pp. 615-626). New York; Thieme Medical Publishers.

John, M.S., Dimitrijevic, A. & Picton, T.W. 2001a. Weighted averaging of steady-state responses. *Clinical Neurophysiology,* 112:555-562.

John, M.S., Dimitrijevic, A. & Picton, T.W. 2002. Auditory steady-state responses to exponential modulation envelopes. *Ear & Hearing, 23*(2):106-117.

John, M.S., Dimitrijevic, A., Van Roon, P. & Picton, T.W. 2001b. Multiple auditory steady-state responses to AM and FM stimuli. *Audiology and Neuro-otology,* 6(1):12-27.

John, M.S., Lins, O.G., Boucher, B.L. & Picton, T.W. 1998. Multiple auditory steady-state responses (MASTER): Stimulus and recording parameters. *Audiology*, 37:59-82.

John, M.S. & Picton, T.W. 2000. Human auditory steady-state responses to amplitude-modulated tones: Phase and latency measurements. *Hearing Research,* 141:57-79.

John, M.S. & Picton, T.W. 2000. MASTER: A Windows program for recording multiple auditory steady-state responses. *Computer Methods and Programs in Biomedicine,* 61:125-150.

Johnson, K.O., Work, W.P. & McCoy, G. 1956. Functional deafness. *The Annals of Otology, Rhinology & Laryngology,* 65:154-170.

Johnson, T.A. & Brown, C.J. 2001. *Preliminary results using the ERA device to measure auditory steady-state response thresholds: Comparing audiometric, ASSR and ABR thresholds in adults*. Poster presentation, 17th Biennial Symposium, International Evoked Response Audiometry Study Group, Vancouver, Canada.

Johnston, J.M. & Pennypacker, H.S. 1993. *Strategies and tactics of behavioural research (*2nd ed.). New Jersey: Lawrence Erlbaum.

Key, J.P. 1997. Research design in occupational education. http//www.okstate.edu/ag/agedem4h/academic/aged5980a/5980/newpage2.htm (retrieved 29 January 2004).

Kimura, J. 1985. Abuse and misuse of evoked potentials as a diagnostic tool. *Archives of Neurology,* 42:78-80.

Kraus, N., Kileny, P. & McGee, T. 1994. Middle latency auditory evoked potentials. In J. Katz (Ed.),. *Handbook of clinical audiology* (4th ed., pp. 387-402.). Baltimore: Williams & Wilkins.

Kuwada, S., Batra, R. & Maher, V.L. 1986. Scalp potentials of normal and hearing impaired subjects in response to sinusoidally amplitude modulated tones. *Hearing Research,* 21:179-192.

Kvaerner, K.J., Engdahl, B., Aursnes, J., Arnesen, A.R. & Mair, I.W.S. 1996. Transient-evoked otoacoustic emissions: Helpful tool in the detection of pseudohypacusis. *Scandinavian Audiology,* 25:173-177.

Larsen, C.R. 1998. *HIV-1 and communication disorders: What speech and hearing professionals need to know*. San Diego, CA: Singular.

Leedy, P.D. 1974. *Practical research: Planning and design.* New York: Macmillan.

Leedy, P.D. 1997. *Practical research: planning and design (*6th ed.). Englewood Cliffs, NJ: Prentice Hall.

Levin, J. 2002, September. Personal communication, Biostatistics Unit, Medical Research Council, University of Pretoria.

Levin, J. 2003, February. Personal communication, Biostatistics Unit, Medical Research Council, University of Pretoria.

Lins, O.G. & Picton, T.W. 1995. Auditory steady-state responses to multiple simultaneous stimuli. *Electroencephalography and clinical Neurophysiology,* 96:420-432.

Lins, O.G., Picton, T.W., Boucher, B.L., Durieux-Smith, A., Champagne, S.C., Moran, L.M., Perez-Abalo, M.C., Martin, V. & Savio, G. 1996. Frequency-specific audiometry using steady-state responses*. Ear & Hearing,* 17(2):81-96.

Lins, O.G., Picton, P.E., Picton, T.W., Champagne, S.C. & Durieux-Smith, A. 1995. Auditory steady-state responses to tones amplitude-modulated at 80 – 110 Hz. *Journal of the Acoustic Society of America,* 97(5):3051-3063.

Lundborg, T. (Ed.). 1981, 7-8 April. *Scandinavian Audiology Supplementum 13: Scandinavian Symposium on Brain Stem Response (ABR).* Stockholm, , 1981.

Maiste, A. & Picton, T.W. 1989. Human auditory evoked potentials to frequency-modulated tones. *Ear & Hearing,* 10:153-160.

Martin, F.N. 2000. Pseudohypacusis. In J. Katz (Ed.), *Handbook of clinical audiology* (pp. 584-595). Boston: Allyn & Bacon.

Martin, F.N. 1994. Pseudohypacusis. In J. Katz (Ed.), *Handbook of clinical audiology* (pp. 553-567). Baltimore: Williams & Wilkens.

MASTER (Multiple Auditory Steady-State Evoked Responses) homepage, [Online], Available: http://www.rotman-baycrest.on.ca/users/sasha_j/master/index.htm# [retrieved 10 October 2001].

McCandless, G.A. & Lentz, W.E. 1968. Evoked response (EEG) audiometry in non-organic hearing loss. *Archives of Otolarynology,* 87:27-32.

McNaghten, A.D., Pei-Chun, T.W. & Dworkin, M.S. 2001. Prevalence of hearing loss in a cohort of HIV-infected patients. *Archives of Otolaryngology: Head & Neck Surgery,* 127:1516-1518.

McPherson, D.L. 1996. *Late potentials of the auditory system.* San Diego, CA: Singular.

McPherson, D.H. & Ballachanda, B. 2000. Middle and long latency auditory evoked potentials. In R.J. Roeser, H. Valente & H. Hosford-Dunn (Eds.), *Audiology diagnosis* (pp. 471-502). New York: Thieme Medical Publishers.

Mc Pherson, D.L. & Star, A. 1993. Auditory evoked potentials in the clinic. In A.M. Halliday (Ed.), *Evoked potentials in clinical testing*. (pp. 359-381). New York: Churchill Livingstone.

Mouton, J. 1989. *Navorsingsmetodologie van die geesteswetenskappe: Basiese begrippe*. Pretoriua: J.C. Insto-Print.

Mouton, J. 2001. *How to succeed in your Master's and doctoral studies: A South African guide and resource book.* Pretoria: Van Schaik.

Mueller, H.G. & Hall, J.W. 1997. *Audiologists' desk reference (Vol. I): Diagnostic audiology: principles, procedures, and practices.* San Diego, CA: Singular.

Mueller, H.G. & Hall, J.W. 1998. *Audiologists' desk reference (Vol. II): Audiologic management, rehabilitation, and terminology.* San Diego, CA: Singular.

Naunton, R.F. & Fernàndez, C. 1978. *Evoked electrical activity in the auditory nervous system.* New York: Academic Press.

Neuman, W.L. 1997. *Social research methods: Qualitative and quantitative approaches (*3rd ed.). Boston: Allyn & Bacon.

Nissly, B. (nissly@attglobal.net). (6 November 2002). Re: *Test condition for Master.* E-mail to E. de Koker (edekoker@webmail.co.za).

Northern, J.L. & Downs, M.P. 1991. *Hearing in children (*4th ed.). Baltimore:Williams & Wilkens.

Oates, P. & Stapells, D.R. 1998. Auditory brainstem response estimates of the pure-tone audiogram: Current status. *Seminars in Hearing,* 19(1):61-81.

Odendaal, W. 2002, 6 September. *South African Association of Audiologists Conference: Industrial hearing tests (new instructions), Midrand.* Pretoria: South African Association of Audiologists.

Odendaal, W. 2003, 20 February. Personal communication, Ear-, Nose- and Throat Specialist, Rustenburg.

Pantev, C., Roberts, L.E., Elbert, T., Rob, B. & Wienbruch, C. 1996. Tonotopic organization of the sources of human auditory steady-state responses. *Hearing Research,* 101:62-74.

Perez-Abalo, M.C., Savio, G.,Torres, A. Martin, V.,Rodriguez, E. & Galan, L. 2001. Steady-state responses to multiple amplitude-modulated tones: An optimized method to test frequency-specific thresholds in hearing-impaired children and normal-hearing subjects. *Ear & Hearing,* 22(3):200-211.

Picton, T. 1987. Human auditory steady-state. In C. Barber & T. Blum (Eds.), *Evoked potentials III* (pp. 117-124). Nottingham: IEPS Publications.

Picton, T.W. 1991. Clinical usefulness of auditory evoked potentials. A critical evaluation. *JSLPA,* 15:3-18.

Picton, T.W. 2001. What are auditory evoked potentials? http://www.audiospeech.ubc.ca.haplab/aep.htm (retrieved 30 May 2002).

Picton, T.W., Dimitrijevic, A., John, M.S. & Van Roon, P. 2001. The use of phase in the detection of auditory steady-state responses. *Clinical Neurophysiology,* 112:1698-1711.

Picton, T.W., Kohn, S.J., Dimitrijevic, A. & Purcell, D. 2003. Human auditory steady-state responses. *International Journal of Audiology,* 42:177-219.

Picton, T. & Scherg, M. 1990. Auditory evoked potentials. In C. Barber & M.J. Taylor (Eds.*), Evoked potential review.* Nottingham: IEPS Publications.

Picton, T.W., Skinner, C.R., Champagne, S.C., Kellet, A.J.C. & Maiste, A.C. 1987. Potentials evoked by the sinusoidal modulation of the amplitude or frequency of a tone. *Journal of the Acoustic Society of America,* 82(1):65-177.

Plinkert, P., Hemmer, W., Wagner, W., Just, K. & Zener, H.P. 1999. Monitoring noise susceptibility: sensitivity of oto-acoustic emissions and subjective audiometry. *British Journal of Audiology,* 33:367-382.

Plourde, G. & Picton, T.W. 1990. Human auditory steady-state response during general anesthesia. *Anesthesia Analgesics,* 71:460-468.

Qiu, W.W., Stucker, F.J., Shengguang, S.Y. & Welsh, L.W. 1998. Current evaluation of pseudohypacusis: Strategies and classification. *The Annals of Otology, Rhinology and Laryngology,* 107(8):38-647.

Ramantsi, M. 2002. Noise induced hearing loss: Instruction 171 and supplement. *Occupational Health,* 8(5):28-29.

Rance, G., Dowell, R.C., Rickards, F.W., Beer, D.E. & Clark, G.M. 1998. Steady-state evoked potential and behavioural hearing thresholds in a group of children with absent click-evoked auditory brain stem response. *Ear & Hearing,* 19(1):48-61.

Rance, G., Rickards, F.W., Cohen, L.T., Burton, M.N., & Clark, G.M. 1993. Steady-state evoked potentials: A new tool for the accurate assessment of hearing in cochlear implant candidates. A*dvances in Oto-Rhino-Laryngology,* 48:44-48.

Rance, G., Rickards, F.W., Cohen, L.Y., De Vidi, S. & Clark, G.M. 1995. Automated prediction of hearing thresholds in sleeping subjects using auditory steady-state evoked potentials. *Ear & Hearing,* 16:499-507.

Reneau, J.P. & Hnatiow, G. Z. 1975. *Evoked response audiometry: A topical and historical review.* Baltimore: University Park Press.

Republic of South Africa, Department of Labour. 1995. *WCC: Internal instruction 168: Determination of disability in cases of noise induced hearing loss.* Pretoria: Workmen's Compensation Commissioner.

Republic of South Africa, Department of Labour. 2000. *WCC: Instruction 171: Determination of disability in cases of noise induced hearing loss*. Pretoria: Workmen's Compensation Commissioner.

Republic of South Africa, Department of Minerals and Energy. 1996. *Mine Health and Safety Act No 29 of 1996*. Pretoria: Government Printer.

Rickards, F.W. & Clark, G.M. 1984. Steady-state evoked potentials to amplitude-modulated tones. In R.H. Nodar & C. Barber (Eds.), *Evoked potentials II* (pp. 163-168). Boston: Butterworth.

Rickards, F.W. & De Vidi, S. 1995. Exaggerated hearing loss in noise-induced hearing loss compensation claims in Victoria. *The Medical Journal of Australia,* 163:360-363.

Rickards, F.W., De Vidi, S. & McMahon, D.S. 1996. Cortical evoked response audiometry in noise induced hearing loss claims. *Australian Journal of Otolaryngology*, 2:237-241.

Rickards, F.W., Tan, L.E., Cohen, L.T., Wilson, O.J., Drew, J.H. & Clark, G.M. 1994. Auditory steady-state potential in newborns. *British Journal of Audiology,* 28:327-337.

Rintelmann, W.F., Schwan, S.A. & Blakley, B.W. 1991. Pseudohypacusis. *Ototlaryngologic Clinics of North America,* 24(2):381-390.

RMA guidelines. 2003. (www.randmutual.co.za) re: noise induced hearing loss. (retrieved 17 June 2003).

Rob, B., Borgmann, C., Draganova, R., Roberts, L.E. & Pantev, C. 2000. High-precision magnetoencephalographic study of human auditory steady-state responses to amplitude-modulated tones. *Journal of the Acoustic Society of America,* 108(2):679-691.

Robinson, M., & Kasden, S.D. 1973. Clinical application of pure-tone delayed auditory feedback in pseudohypocusis. *The Eye, Ear, Nose and Throat Monthly,* 52:31-33.

Rodriguez, R., Picton, T., Linden, D., Hamel, G. & Laframboise, G. 1986. Human auditory steady-state responses: Effects of intensity and frequency. *Ear & Hearing,* 7(5):300-313.

Roeser, R.J., Buckley, K.A. & Sichney, G.S. 2000a. Pure-tone tests. In R.J. Roeser, M. Valente & H. Hosford-Dunn (Eds.), *Audiology diagnosis* (pp. 227–252). New York: Thieme Medical Publishers,

Roeser, R.J., Valente, M. & Hosford-Dunn, H. 2000b. Diagnostic procedures in the profession of Audiology. In R.J. Roeser, M. Valente & H. Hosford-Dunn (Eds.), *Audiology diagnosis* (pp.1-18). New York: Thieme Medical Publishers.

Ross, M. 1964. The variable intensity pulse count method (VIPCM) for the detection and measurement of children with functional hearing losses. *Journal of Speech and Hearing Disorders,* 29:477-482.

Saban, Y. (ysaban@blsc.com) (1 November 2002). Re: *Number of sweeps to stop a test.* E-mail to E. de Koker (edekoker@webmail.co.za).

Santarelli, R. & Conti, G. 1999. Generation of auditory steady-state responses. *Scandinavian Audiology,* 28(51):23-32.

Savio, G., Càrdenas,J., Abalo, M.P., Gonzàlez, A. & Valdès, J. 2001. The low and high frequency auditory steady-state responses mature at different rates. *Audiology and Neuro-Otology,* 6(5):279-287.

Schlauch, R.S., Arnce, K..D., Olson, L.M., Sanchez, S. & Doyle, T.N. 1996. Identification of pseudohypacusis using speech recognition thresholds. *Ear & Hearing,* 17(3):229-236.

Schmulian, D. 2002. The prediction of hearing thresholds with dichotic multiple frequency steady-state evoked potentials compared to an auditory brainstem response protocol. Unpublished Phd thesis, University Pretoria.

Simonton, K.M. 1965. Audiometry and diagnosis. In A. Slorig (Ed.), *Principles and practices.* (pp. 185-206). Baltimore: Williams & Wilkins.

Sininger, Y.S. & Cone-Wesson, B. 1994. Threshold prediction using auditory brainstem response and steady-state evoked potentials with infants and young children. In J.P. Katz (Ed.), *Handbook of clinical audiology* (4th ed.) (pp. 298-321). Baltimore: Williams & Wilkins.

Sininger, Y.S. & Cone-Wesson, B. 2002. Threshold prediction using auditory brainstem response and steady-state evoked potentials with infants and young children. In J.P. Katz (Ed.), *Handbook of clinical audiology* (5th ed.). Philadelphia: Williams & Wilkens.

Sohmer, H. & Kinarti, R. 1984. Survey of attempts to use auditory evoked potentials to obtain an audiogram. *British Journal of audiology,* 18:237-244.

Stach, B.A. 1998. *Clinical audiology: An introduction.* San Diego, CA: Singular.

Stapells, D.R., Linden, D., Suffield, J.B., Hamel, G. & Picton, T.W. 1984. Human auditory steady-state potentials. *Ear & Hearing,* 5(2):105-113.

Stapells, D.R., Picton, T.W., Durieux-Smith, A., Edwards, C.G. & Moran, L.M. 1990. Thresholds for short-latency auditory evoked potentials to tones in notched noise from infants and young children with normal hearing and hearing impaired subjects. *Audiology,* 29:262-274.

Strydom, H. 2002. Ethical aspects of research in the social sciences and human services professions. In A.S. De Vos (Ed.), *Research at grass roots: For the social sciences and human service professions* (2nd ed., pp. 62-76). Pretoria: Van Schaik.

Swanepoel, D.W. 2001. *Estimating pure-tone behavioural thresholds with the dichotic multiple frequency auditory steady-state response compared to an auditory brainstem response protocol in normal hearing adults*. Unpublished M Communication Pathology thesis, University of Pretoria.

Thorton, C., Heneghan, C.P.H., James, M.F.M. & Jones, J.G. 1984. The effects of halothane and enflurane anesthesia on the early auditory evoked potentials in humans. *Evoked potentials II* (pp. 483-489). Boston: Butterworth.

Trier, T & Levy, R. 1965. Social and psychological characteristics of veterans with functional hearing loss. *Journal of Audiological Research*. 5:241-355.

Valdez, J.L., Perez-Abalo, M.C., Martin, V., Savio, G., Sierra, C., Rodriguez, E. & Lins, O. 1997. Comparison of statistical indicators for the automatic detection of 80 Hz auditory steady-state responses. *Ear & Hearing,* 18(5):420-429.

Verster, J. 2002, 28 May. *Steady-state evoked potentials: A tool for frequency-specific hearing assessment, Pretoria.*

Wackerly, D.D., Menderhall, W. & Schaeffer, R.L. 1996. *Mathematical statistics with applications.* Belmont, CA: Duxbury Press.

Weber, B. 1994. Auditory brainstem response: Threshold estimation and auditory screening. In P.J. Katz (Ed.), *Handbook of clinical audiology* (4th ed., pp. 375-385). Baltimore: Williams & Wilkens.

Workmen's Compensation Commissioner. 1995. *Internal instruction 168: Determination of disability in cases of noise induced hearing loss.* Pretoria: Government Printer.

Workmen's Compensation Commissioner. 2000. *Internal instruction 171: Determination of disability in cases of noise induced hearing loss.* Pretoria: Government Printer.

APPENDIX A

INFORMED CONSENT

Informed consent Simhealth 02 07 01: **Background information and request for consent of workers asked to participate**

This form is to be administered to selected workers before their participation in audiometric and ASSR testing by the audiologists.

Read the following to each prospective subject, pausing to answer any questions:

This mine has agreed to help the SIMRAC research team investigate how certain hearing tests might be helpful in identifying noise-induced hearing loss. Information from the study will be used to decide if changes can be made to normal testing procedures that will allow better identification of hearing losses caused by noise, in order to improve workers' health and safety. The study has been approved by the Union, because all of the workers who agree to participate will remain unanimous, and the results will be used to help protect workers from noise.

If you agree to participate, we will ask you some questions about you, any problems that you might have experienced with your hearing, your job and the noise in places on the mine where you work.

Your hearing will then be tested in the normal way, after which some special tests will be used to check your hearing. Comparisons will be made between results from the normal tests and from the special tests, to find out if the special tests would be better for identifying and describing hearing loss caused by noise.

The experiment is not meant to check your hearing, but to find out the best way of testing ears. Accordingly, the tests and the results will have no effect on your job, and will have nothing to do with compensation. Your test results will be kept confidential, and only you and the research team will be able to look at them. The results will be used to find out if the new tests are helpful in the correct description and identification of noise-induced hearing loss.

We will explain to you the way each test is done, we will show you the results and we will explain what they mean. Some of the tests will be done more than once, to double-check on the results.

We will keep your name and any information you tell us in strict confidence, and not tell the mine or the managers anything about you or your test results.

Your participation in the study is voluntary. If you do not want to take part, it will not affect your job in any way. If you do decide to take part, this will also not affect your job in any way, but will be helpful to all workers who are working in the noise. We ask that you decide for yourself whether you want to participate, and if you have some questions that need to be answered before you decide, please ask them.

Will you help us with this research? (*YES or NO*)

If NO, ask the next worker. If YES, ask worker to sign or make a mark in the space below to indicate that he has been given the information and understands it. Then record the other details.

……

I have been told about the study and have been given the chance to ask questions about it and about my participation. I also understand that if I have any questions at any time, they will be answered, and that if I am not satisfied with the answers I can withdraw from the study.

Name:…….. Company number: ……

Date:……..

APPENDIX B

CONSENT-VALIUM

Informed consent Simhealth 02 07 01: **Background information and request for consent of workers asked to participate.**

This form is to be administered to selected workers before their participation in audiometric and ASSR testing by the audiologists.

Read the following to each prospective subject, pausing to answer any questions:

This mine has agreed to help the SIMRAC research team investigate how certain hearing tests might be helpful in identifying noise-induced hearing loss. Information from the study will be used to decide if changes can be made to normal testing procedures that will allow better identification of hearing losses caused by noise, in order to improve workers' health and safety. The study has been approved by the Union, because all of the workers who agree to participate will remain unanimous, and the results will be used to help protect workers from noise.

If you agree to participate, we will ask you some questions about you, any problems that you might have experienced with your hearing, your job and the noise in places on the mine where you work.

Your hearing will then be tested in the normal way, after which some special tests will be used to check your hearing. Comparisons will be made between results from the normal tests and from the special tests, to find out if the special tests would be better for identifying and describing hearing loss caused by noise.

The experiment is not meant to check your hearing, but to find out the best way of testing ears. Accordingly, the tests and the results will have no effect on your job, and will have nothing to do with compensation. Your test results will be kept confidential, and only you and the research team will be able to look at them. The results will be used to find out if the new tests are helpful in the correct description and identification of noise-induced hearing loss.

We will explain to you the way each test is done, we will show you the results and we will explain what they mean. Some of the tests will be done more than once, to double-check on the results.

We will keep your name and any information you tell us in strict confidence, and not tell the mine or the managers anything about you or your test results.

Your participation in the study is voluntary. If you do not want to take part, it will not affect your job in any way. If you do decide to take part, this will also not affect your job in any way, but will be helpful to all workers who are working in the noise. We ask that you decide for yourself whether you want to participate, and if you have some questions that need to be answered before you decide, please ask them.

I agree to taking medicine (10mg of Valium) to help me relax during the test

Will you help us with this research? (*YES or NO*)

If NO, ask the next worker. If YES, ask worker to sign or make a mark in the space below to indicate that he has been given the information and understands it. Then record the other details.

……

I have been told about the study and have been given the chance to ask questions about it and about my participation. I also understand that if I have any questions at any time, they will be answered, and that if I am not satisfied with the answers I can withdraw from the study.

Name:…….. Company number: ……

Date:……

Patient information sheet

ASSR tests: VALIUM

1. **Thank you for agreeing to participate in this study.**
2. **The medicine that you have agreed to take will make you feel sleepy/drowsy. There is a bed available where you can lie down.**
3. **During the test you will also lie down and be able to sleep/rest. The test will take an hour.**
4. **After completion of the test you will be transported back to your hostel**
5. **Please refrain from driving a car. Remain at the hostel for the duration of today. Do sleep or rest.**
6. **You are not required to work today and will receive a shift.**

APPENDIX C

GOLD FIELDS

OCCUPATIONAL MEDICINE

Gold Fields Ltd
c/o Gold Fields Trust (Pty) Ltd
Reg. 1982/004673/07
Private Bag X11
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Cell +27 83 407 4624
stuart.shearer@goldfields.co.za

12 August.2002

Elize de Koker
PO Box 3397
Kenmare
1745

Dear Elize

Re: An assessment of the clinical value of auditory steady state responses in the audiological evaluation of noise-induced hearing loss in the South African mining industry

This is to confirm that you have my consent to conduct this SIMRAC study (SIM 020701) at Driefontein Occupational Health Centre conditional on your receiving Ethical Committee approval from a recognised authority.

Permission is granted to examine the medical surveillance records of the study subjects conditional on written consent being obtained from each subject.

I should be grateful if you would provide me with copies of the ethical approval and the consent form prior to embarking on the study.

With kind regards

Yours sincerely

Dr Stuart Shearer
Senior Consultant: Occupational Medicine

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HARMONY
GOLD MINING CO.
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12 August, 2002

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PO Box 3397
Kenmare
1745

Dear Elize

Re An assessment of the clinical value of auditory steady state responses in the audiological evaluation of noise induced hearing loss in the South African mining industry

This is to confirm that you have my consent to conduct this SIMRAC study (SIM 020701) at Phumlani Occupational Health centre conditional on your receiving Ethical Committee approval from a recognised authority.

Permission is granted to examine the medical surveillance records of the study subjects, conditional on written informed consent being obtained from each subject.

I should be grateful if you would provide me with copies of the Ethical approval and the consent form prior to embarking on the study.

With kind regards

Yours sincerely

Dr J Geyser

Manager Occupational health

University of Pretoria

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

Department of Communication Pathology
Speech, Voice and Hearing Clinic

29 August, 2002

Ms E de Koker
P.O. Box 3397
Kenmare
KRUGERSDORP
1745

Dear Ms De Koker

APPLICATION: CLEARANCE ETHICS COMMITTEE

Your application to the Research Ethics Committee of the Faculty of Humanities regarding ethical procedures for your PhD (Communication Pathology was reviewed in August, 2002.

We have the pleasure of informing you that your application with the title ***"Dichotic Multiple Frequency Steady State Response Audiomety: a diagnostic tool within the mining environment"*** has been approved.

We wish you every success in conducting your research.

Sincerely

B Louw

Prof. B Louw
CHAIR: RESEARCH ETHICS COMMITTEE
FACULTY OF HUMANITIES

cc. Prof. René Hugo
Department Communication Pathology

APPENDIX F

Safety In Mines Research Advisory Committee

Facilitating safety and health research in the South African mining industry

SIMRAC

Chairman:	(012) 317 9125
Project Support Services:	
Programme Manager	(011) 358 9180
Administration	(011) 358 9182
Telefax:	(011) 4031821
Address:	P Bag X63 Braamfontein 2017
E- mail:	cjones@simpross.co.za

2 May 2001

Healing Centre
Ms E de Koker
Gehoorsentrum@icon.co.za

Dear Sir

Award of SIMRAC Project

I am pleased to inform you that your **Proposal** on the **Project** "Feasibility of using oto-acoustic emission (OAE) methods for screening early hearing impairment in South African mineworkers" Ref No. HEALTH 802 dated 5 October 2000, to the amount of R1 160 400 has been accepted by the **Chief Inspector**, as indicated in the attached **Memorandum of Agreement**. The **Memorandum** and **Approved Proposal** constitute the Contract in terms of which the Project shall be conducted.

The **Contract** will come into effect on the date of the signing of the **Memorandum** by an authorised person on behalf of the **Proposer.**

Please return the signed (and page initialed) **Contract together with your original signed proposal** to the Research Manager at 2nd Floor, Braamfontein Centre, 23 Jorrisen Street, Braamfontein (Private Bag X63, Braamfontein 2017), as well as an electronic copy of the Research Proposal in the prescribed format, attached hereto, as soon as possible.

In all communications regarding the **Project,** the **Project** title and reference number must be clearly stated.

NB : To expedite payment all invoices are to be made out to "Mine Safety Research" and are only to be forwarded to this office on receipt of an "Order for Invoice"

Yours faithfully,

Ms M Hermanus
Chief Inspector of Mines

APPENDIX G

CASE HISTORY (RESEARCH QUESTIONNAIRE)

ASSR

Research questionnaire

Ind no. : _____

Study no. : _____

Date : _____

Date of birth : _____

Mine : _____

Audiologist : _____

1. **Otoscopy**

Landmarks	L	R
Cone of light	_____	

Cerumen	L	R
Occluding	_____	
Minimal	_____	
Excessive	_____	
None	_____	

Tympanic membrane	L	R
Normal	_____	
Dull	_____	
Perforated	_____	
Scarring	_____	

External canal	L	R
Normal	_____	
Red/Swollen	_____	
Foreign body	_____	
Growth	_____	
Drainage	_____	
Blood	_____	
Collapsed	_____	

2. **Immittance measurements**

	L	R
Compliance	_____	
Volume	_____	
Pressure	_____	
Reflex ipsilateral 1000 Hz	_____	

3. **Specific ear and medical history**

Head injuries:

Blow to head, accidents

Ear operations:

_____

Injury to ears:

Blood draining from ear

_____

Barotrauma:

- Medical history
- Air from ear when blowing nose

_____

Middle ear pathology:

Ear infections

- Pain
- Discharge

_____

Ototoxic drugs:

- TB
- Malaria
- Intensive care

_____

Job history:

- Years underground
- Job description

4. **Diagnostic audiogram:**

Attach copy of diagnostic audiogram

5. **ASSR estimated audiogram**

Attach copy of printout

Time taken to complete ASSR test_____

Type ASSR test _____

6. **Comparison of pure-tone and ASSR threshold**

Left ear **Right ear**

KHz **KHz**

Description	Date	.5 KHz	1	2	3	4	.5	1	2	3	4
ASSR threshold											
Pure tone-thres-hold											

Certificate of Calibration

This is to certify that on August , 30 2002

GSI 38V2 Auto Tymp

Serial Number : 989057

was calibrated by NS Clinical Technologies (Pty) Ltd.

The above instrument complies with:

☑ IEC 1027 : Instruments for the measurement of Aural acoustic Impedance / Admittance

☑ IEC 601 – 1 : Safety of Medical Electric Equipment

Calibration Officer: W. de Klerk Signature:

Certificate of Calibration

This is to certify that on August , 30 2002

AccuTymp 100

Serial Number : 252150

was calibrated by NS Clinical Technologies (Pty) Ltd.

The above instrument complies with:

☑ IEC 1027 : Instruments for the measurement of Aural acoustic Impedance / Admittance

☑ IEC 601 – 1 : Safety of Medical Electric Equipment

Calibration Officer: W. DE KLERK Signature:

NS CLINICAL TECHNOLOGIES PTY LTD

P O Box 202
Groenkloof
Pretoria
South Africa
0027

338 Eridanus Street
Waterkloof Ridge
Pretoria
South Africa
0181

Tel : + 27 [012] 460-7676
Fax : + 27 [012] 460-7676

AUDIOMETER CALIBRATION CERTIFICATE

Calibration Officer: **WILLIAM DE KLERK**	Cert. No: 558/NS/2002

SITE OF CALIBRATION

Company	ELIZE DE KOKER
Address	P O BOX 3397
	KENMERE
	1745

UNIT UNDER CALIBRATION

SUBJECT	MAKE	MODEL	SERIAL NO.
Audiometer	MADSEN	OB 822	26644
Earphone Left	TELEPHONICS	TDH-39P	C 38929
Earphone Right	TELEPHONICS	TDH-39P	C 38923
Bone Vibrator	RADIO EAR	B 71	1886448

CALBRATION EQUIPMENT

ITEM	MODEL	SERIAL NO.
Sound Level Meter	Quest 1800	HP 8110015
Sound Level Calibrator	Quest QC-20	QO 9090053
1/3 Octave Filter	Quest OB-300	HV 8120023
Frequency Counter	Fluke 87	52151118
Artificial Ear	Bruël & Kjaer 4153	1509914
Artificial Mastoid	Bruel & Kjaer 4930	1727445
Calibration date : DECEMBER 2001	Calibration Cert.No: 2001-361De Beer Calibration Services	

TEST ENVIRONMENT CONDITIONS

Wide Band Background Noise Level: 68.4 dB.	Background Noise Level @ 4000Hz: 20.3 dB
Calibration Signal: Before: 114.0 dB.	Calibration Signal: After: 114.0 dB.

COMPLIANCE OF EQUIPMENT

1. This audiometer is hereby certified as calibrated in accordance with SABS 0154-1&2:1996 for Pure-tone Audiometers.	YES
2. This audiometer is hereby certified as calibrated in accordance with ISO 389-4 for Narrow Band and Masking Noise.	YES
3. This audiometer is hereby certified as calibrated in accordance with ISO 389-7 for Sound Field System.	NO
4. This audiometer is hereby certified as calibrated in accordance with IEC 645-2 for Speech Audiometry.	YES
5. **Remarks : This certificate was issued at : DRIEFONTEIN MINE**	
Certificate expires on:	30-08-2003

NOTES

1.This certificate is valid for a period of 12 months(subject to exceptions given in SABS 0154-1996,section 6)
2.This certificate relates only to the specific item(s) listed above and does not imply compliance in respect of a similar item that has not been examined.
3. While every endeavour is made to ensure that this certificate is accurate, NS Clinical Technologies PTY LTD or its representatives shall in no way be liable for any errors, whether in fact or opinion.

SIGNATURE

30-08-2002
DATE

NS CLINICAL TECHNOLOGIES PTY LTD

P O Box 202
Groenkloof
Pretoria
South Africa
0027

338 Eridanus Street
Waterkloof Ridge
Pretoria
South Africa
0181

Tel : + 27 [012] 460-7676
Fax : + 27 [012] 460-7676

AUDIOMETER CALIBRATION CERTIFICATE

Calibration Officer: **WILLIAM DE KLERK**	Cert. No: 443/NS/2002

SITE OF CALIBRATION

Company	ELIZE DE KOKER – PHUMLANI HEARCARE
Address	P O BOX 3397
	KENMERE
	1745

UNIT UNDER CALIBRATION

SUBJECT	MAKE	MODEL	SERIAL NO.
Audiometer	GSI	61	981496
Earphone Left	TELEPHONICS	TDH-50P	C 02184
Earphone Right	TELEPHONICS	TDH-50P	C 02188
Bone Vibrator	RADIO EAR	B 71	--------

CALBRATION EQUIPMENT

ITEM	MODEL	SERIAL NO.
Sound Level Meter	Quest 1800	HP 8110015
Sound Level Calibrator	Quest QC-20	QO 9090053
1/3 Octave Filter	Quest OB-300	HV 8120023
Frequency Counter	Fluke 87	52151118
Artificial Ear	Bruël & Kjaer 4153	1509914
Artificial Mastoid	Bruel & Kjaer 4930	1727445
Calibration date : DECEMBER 2001	Calibration Cert.No: 2001-361De Beer Calibration Services	

TEST ENVIRONMENT CONDITIONS

Wide Band Background Noise Level: 69.9 dB.	Background Noise Level @ 4000Hz: 20.3 dB
Calibration Signal: Before: 114.0 dB.	Calibration Signal: After: 114.0 dB.

COMPLIANCE OF EQUIPMENT

1. This audiometer is hereby certified as calibrated in accordance with SABS 0154-1&2:1996 for Pure-tone Audiometers.	YES
2. This audiometer is hereby certified as calibrated in accordance with ISO 389-4 for Narrow Band and Masking Noise.	YES
3. This audiometer is hereby certified as calibrated in accordance with ISO 389-7 for Sound Field System.	NO
4. This audiometer is hereby certified as calibrated in accordance with IEC 645-2 for Speech Audiometry.	YES
5. **Remarks :** ----------	
Certificate expires on:	30-08-2003

NOTES

1.This certificate is valid for a period of 12 months(subject to exceptions given in SABS 0154-1996,section 6)
2.This certificate relates only to the specific item(s) listed above and does not imply compliance in respect of a similar item that has not been examined.
3. While every endeavour is made to ensure that this certificate is accurate, NS Clinical Technologies PTY LTD or its representatives shall in no way be liable for any errors, whether in fact or opinion.

SIGNATURE

30-08-2002
DATE

NS CLINICAL TECHNOLOGIES PTY LTD

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Pretoria
South Africa
0027

338 Eridanus Street
Waterkloof Ridge
Pretoria
South Africa
0181

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Fax : + 27 [012] 460-7676

30 August 2002

Att : Elize de Koker

P O BOX 3397
KENMERE
1745

EVALUATION OF AUDIOMETRIC TEST SITE

1. Purpose of Test

To determine if the proposed site would meet the requirements of *SABS Code of Practice 0182-1998* "Obtaining an Acoustic Environment suitable for Diagnostic Audiometric Testing".

2. Test Site

The sound level measurements were performed by Mr W de Klerk on 30 August 2002 at Driefontein Mine. The sound level measurements were performed inside the Audiometric Test Enclosure.

3. Test Equipment

1.	Sound Level Meter:	Quest 1800	#HP 8110015
2.	Sound Level Calibrator:	Quest QC-20	#QO 9090053
3.	Octave Band Filter:	Quest OB300	#HV 8120023
4.	Microphone:	B & K 4134	#1743885

The equipment was certified as accurate by De Beer Calibration Services in December 2001. The calibration certificate number for the above mentioned equipment is 2001-361.

Calibration Signal: Before: 114,0dB After: 114,0dB.

4. Test Procedure

The test procedure outlined in SABS 0182-1998 paragraph 5.5 was followed to obtain the readings noted in table 1.

5. Test Results

Octave Band Frequencies (Hz)	Maximum Sound Pressure Level Allowed in dB (SABS – 0182)	Sound Pressure Levels Obtained at Test Site (dB)
125	29.0	27.8
250	21.0	20.0
500	20.5	19.4
1000	24.0	13.2
2000	31.0	12.1
4000	37.0	12.2
8000	35.5	13.8

TABLE .1

6. Conclusion

As can be seen from the above results the measured sound pressure levels are all below the recommended sound pressure levels for diagnostic audiometry according to SABS 0182-1998. The audiometric booth is therefore suitable for diagnostic audiometry, at the site mentioned in point 2 of this report.

Best Regards

WILLIAM DE KLERK

NS CLINICAL TECHNOLOGIES PTY LTD

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338 Eridanus Street
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Fax : + 27 [012] 460-7676

30 August 2002

Att : Elize de Koker

PHUMLANI HEARCARE
P O BOX 3397
KENMERE
1745

EVALUATION OF AUDIOMETRIC TEST SITE

1. Purpose of Test

To determine if the proposed site would meet the requirements of *SABS Code of Practice 0182-1998* "Obtaining an Acoustic Environment suitable for Diagnostic Audiometric Testing".

2. Test Site

The sound level measurements were performed by Mr W de Klerk on 30 August 2002 at Phumlani Hearcare in Randfontein. The sound level measurements were performed inside the Acousti Booth [L] Audiometric Test Enclosure.

3. Test Equipment

1.	Sound Level Meter:	Quest 1800	#HP 8110015
2.	Sound Level Calibrator:	Quest QC-20	#QO 9090053
3.	Octave Band Filter:	Quest OB300	#HV 8120023
4.	Microphone:	B & K 4134	#1743885

The equipment was certified as accurate by De Beer Calibration Services in December 2001. The calibration certificate number for the above mentioned equipment is 2001-361.

Calibration Signal: Before: 114,0dB After: 114,0dB.

4. Test Procedure

The test procedure outlined in SABS 0182-1998 paragraph 5.5 was followed to obtain the readings noted in table 1.

5. Test Results

Octave Band Frequencies (Hz)	Maximum Sound Pressure Level Allowed in dB (SABS – 0182)	Sound Pressure Levels Obtained at Test Site (dB)
125	29.0	27.2
250	21.0	19.4
500	20.5	18.0
1000	24.0	12.7
2000	31.0	11.9
4000	37.0	11.9
8000	35.5	13.7

TABLE .1

6. Conclusion

As can be seen from the above results the measured sound pressure levels are all below the recommended sound pressure levels for diagnostic audiometry according to SABS 0182-1998. The audiometric booth is therefore suitable for diagnostic audiometry, at the site mentioned in point 2 of this report.

Best Regards

WILLIAM DE KLERK

APPENDIX N

RAW DATA: ASSR AND PURE TONE THRESHOLDS
(Phase 1) (n=81)

	Data Simhealth 02 07 01			LEFT EAR					RIGHT EAR						
Machine	Test	Protocol	Sedation	500 Hz	1000 Hz	2000 Hz	3000 Hz	4000 Hz	500 Hz	1000 Hz	2000 Hz	3000 Hz	4000 Hz	Subject	Time
Audera 1	PT threshold			60	80	60	55	65	40	70	60	55	70	1	min.
	ASSR	Asleep	no	.	.	.	.	.	.	65	60	.	.	1	40
ditto	PT threshold			20	45	55	50	50	20	45	40	40	45	2	
	ASSR	Asleep	no	.	.	.	.	.	15	35	35	.	50	2	42
ditto	PT			35	45	50	35	30	30	40	40	35	30	3	
	ASSR	Asleep	no	.	.	.	.	.	.	30	.	.	45	3	12
ditto	PT			10	50	55	55	60	10	45	50	60	50	4	
	ASSR	Asleep	no	.	.	.	.	.	55	50	65	.	60	4	40
ditto	PT			15	25	45	55	65	20	20	25	50	60	5	
	ASSR	Asleep	no	5	20	45	.	75	.	.	.	.	.	5	52
ditti	PT			5	5	40	65	80	5	10	35	70	70	6	
	ASSR	Asleep	no	.	20	55	.	80	.	.	.	.	.	6	18
ditto	PT	Asleep		15	40	50	75	75	25	30	30	50	55	7	
	ASSR		no	.	.	.	.	.	.	.	.	.	.	7	10
"	Pt	Asleep		15	25	30	35	35	15	30	35	30	30	8	
	ASSR		no	20	.	45	.	.	.	.	.	.	.	8	38
"	PT	Asleep		30	45	45	50	50	25	40	40	45	50	9	
	ASSR		no	.	.	.	.	.	40	40	50	.	50	9	23
"	PT	Asleep		20	20	20	30	35	15	25	20	30	30	10	
	ASSR		no	.	.	.	.	.	.	.	.	.	.	10	46
"	PT			30	45	35	40	45	30	40	45	35	45	11	
	ASSR	Asleep	no	.	.	.	.	.	.	50	.	.	.	11	.
"	Pt			35	40	35	35	40	30	30	20	40	45	12	
	ASSR	Asleep	no	.	.	.	.	.	.	.	.	.	55	12	.
				LEFT EAR					RIGHT EAR						
Machine	Test	Protocol	Sedation	500 Hz	1000 Hz	2000 Hz	3000 Hz	4000 Hz	500 Hz	1000 Hz	2000 Hz	3000 Hz	4000 Hz	Subject	Time
Audera 1	PT			10	15	50	55	55	10	15	50	65	50	13	
	ASSR	Awake	no	10	25	60	.	50	10	20	60	.	60	13	48
ditto	PT			40	45	40	70	75	30	45	35	45	55	14	
	ASSR	Awake	no	.	.	.	.	.	45	50	45	.	70	14	59
	PT			20	45	70	80	70	10	35	60	60	55	15	
ditto	ASSR	Awake	no	.	60	.	.	60	20	60	80	.	70	15	60
	PT			25	35	45	50	50	20	40	45	50	55	16	
"	ASSR	Awake	no	15	30	45	.	50	15	45	50	.	55	16	68
	PT			15	35	40	45	40	5	25	40	45	45	17	
"	ASSR	Awake	no	5	35	45	.	40	5	35	45	.	40	17	70
	PT			25	40	35	30	40	25	40	25	35	35		
"	ASSR	Awake	no	0	40	20	.	30	0	25	15	.	30	18	66
	PT			10	30	45	35	35	5	35	45	35	35		
"	ASSR	Awake	no	.	.	.	.	.	0	35	55	.	25	19	51

				LEFT EAR					RIGHT EAR						
Machine	Test	Protocol	Sedation	500 Hz	1000 Hz	2000 Hz	3000 Hz	4000 Hz	500 Hz	1000 Hz	2000 Hz	3000 Hz	4000 Hz	Subject	Time
	PT			15	35	45	45	40	10	20	35	40	40		
"	ASSR	Awake	no	0	45	50	.	45	15	35	45	.	40	20	67
	PT			15	45	35	25	40	20	50	55	55	50		
"	ASSR	Awake	no	10	40	45	.	55	20	55	60	.	60	21	52
	PT			40	50	55	65	70	25	50	50	60	65		
"	ASSR	Awake	no	35	60	60	.	.	.	.	.	.	.	22	75
	PT			10	30	45	50	50	30	25	40	45	65		
"	ASSR	Awake	no	0	35	50	.	55	20	30	50	.	.	23	35
	PT			50	50	40	15	25	50	50	40	20	15		
"	ASSR	Awake	no	55	60	.	.	30	50	60	.	.	15	24	75
	PT			20	25	45	35	40	5	15	25	25	30		
"	ASSR	Awake	no	15	30	50	.	45	0	20	30	.	25	25	48
	PT			30	45	50	55	55	30	50	50	60	60		
"	ASSR	Awake	no	30	50	50	.	60	20	55	55	.	60	26	63
	PT			20	35	35	40	45	20	35	45	40	45		
"	ASSR	Awake	no	30	45	55	.	60	30	40	60	.	45	27	81
	PT			35	40	35	35	40	30	30	20	40	45		
"	ASSR	Awake	no	.	.	.	.	.	.	.	.	.	55	28	32
				LEFT EAR					RIGHT EAR						
Machine	Test	Protocol	Sedation	500 Hz	1000 Hz	2000 Hz	3000 Hz	4000 Hz	500 Hz	1000 Hz	2000 Hz	3000 Hz	4000 Hz	Subject	Time
	PT			45	55	55	50	50	35	60	55	55	60	29	
Biologic	ASSR	Master	no	50	50	60	.	.	45	.	60	.	.		87
	PT			10	30	40	50	40	15	15	35	45	30	30	
ditto	ASSR	ditto	no	35	40	40	50	40	40	40	.	.	.	.	86
	PT			40	40	35	25	25	45	55	50	50	50	31	
ditto	ASSR	ditto	no	45	40	40	45	.	.	60	35	45	.		77
	PT			20	30	35	35	25	15	30	40	20	25		
"	ASSR	ditto	no	25	40	40	.	20	40	35	30	.	35	32	120
	PT			10	30	50	55	65	10	20	50	50	65		
"	ASSR	ditto	no	20	.	.	.	.	25	40	.	.	65	33	87
	PT			5	15	50	45	45	5	20	35	40	55		
"	ASSR	ditto	no	.	15	.	.	55	.	15	35	.	55	34	80
	PT			30	40	35	30	25	30	25	35	30	40		
"	ASSR	ditto	no	20	25	45	45	50	20	.	45	35	30	35	45
	PT			10	45	60	45	50	5	45	60	55	60		
"	ASSR	ditto	no	35	50	50	45	50	30	30	55	50	70	36	91
	PT			15	25	55	60	80	5	5	35	50	80		
"	ASSR	ditto	no	30	30	65	.	85	30	30	60	.	70	37	120
	PT			30	40	60	65	65	20	25	30	45	55		
"	ASSR	ditto	no	40	45	55	.	.	40	.	30	.	.	38	114
	PT			20	25	30	55	65	15	25	35	60	90		
"	ASSR	ditto	no	.	25	40	.	.	20	40	30	.	.	39	106
	PT			30	40	50	50	55	25	30	50	50	50		
"	ASSR	ditto	no	40	45	45	50	55	50	25	45	30	65	40	90
	PT			30	45	40	50	35	30	35	30	30	45		
"	ASSR	ditto	no	40	35	45	60	30	40	40	35	40	55	41	60
	PT			15	25	45	45	50	20	30	45	55	55		
"	ASSR	ditto	no	40	45	45	60	55	40	35	55	50	.	42	70

Machine	Test	Protocol	Sedation	500 Hz	1000 Hz	2000 Hz	3000 Hz	4000 Hz	500 Hz	1000 Hz	2000 Hz	3000 Hz	4000 Hz	Subject	Time
	PT			15	20	50	45	45	10	25	30	60	65		
"	ASSR	ditto	no	10	20	60	55	.	20	35	40	.	.	43	75
	PT			45	65	65	70	75	45	55	55	65	75		
"	ASSR	ditto	no	50	65	65	.	70	50	45	60	.	.	44	40
	PT			0	30	50	60	55	0	20	30	65	50		
"	ASSR	ditto	no	50	30	.	.	70	55	45	40	.	.	45	75
	PT			10	45	45	50	50	10	35	45	55	40		
"	ASSR	ditto	no	10	45	50	50	45	5	25	50	40	45	46	65
	PT			25	20	35	55	60	20	50	50	45	55		
"	ASSR	ditto	no	30	60	60	.	70	.	60	60	60	.	47	50
	PT			30	45	40	50	40	30	45	40	35	35		
"	ASSR	ditto	no	55	60	55	.	50	50	45	25	55	35	48	68
						LEFT EAR					RIGHT EAR				
Machine	Test	Protocol	Sedation	500 Hz	1000 Hz	2000 Hz	3000 Hz	4000 Hz	500 Hz	1000 Hz	2000 Hz	3000 Hz	4000 Hz	Subject	Time
Audera 2	PT			5	10	30	40	45	10	15	40	40	45		
	ASSR	awake	yes	0	15	40	50	40	0	20	45	45	50	49	
	PT			30	55	60	60	60	35	50	50	60	65		
ditto	ASSR	awake	yes	35	55	60	60	55	30	55	55	50	60	50	45
	PT			15	20	35	40	40	15	30	35	45	50		
ditto	ASSR	awake	yes	30	40	55	.	.	.	.	.	.	.	51	15
	PT			10	20	35	55	50	15	20	35	45	55		
ditto	ASSR	awake	yes	0	30	50	60	50	15	15	50	40	50	52	.
	PT			20	50	50	50	55	30	50	45	45	55		
"	ASSR	awake	yes	.	50	.	.	.	20	45	45	40	45	53	85
	PT			15	65	75	70	65	30	65	75	75	80		
ditto	ASSR	awake	yes	10	65	70	70	75	30	65	85	80	.	54	60
	PT			5	20	30	35	40	20	30	50	55	50		
ditto	ASSR	awake	yes	0	20	40	40	40	35	40	50	45	50	55	45
	PT			15	40	45	55	50	15	45	55	50	50		
"	ASSR	awake	yes	15	55	55	50	50	15	50	65	60	60	56	60
	PT			25	45	55	60	65	25	35	55	65	65		
"	ASSR	awake	yes	30	55	55	60	60	15	35	55	55	55	57	58
	PT			5	15	15	85	85	15	20	10	75	85		
"	ASSR	awake	yes	10	30	.	100	105	20	30	45	.	105	58	62
	PT			30	35	30	50	60	30	45	45	55	50		
"	ASSR	awake	yes	35	55	65	65	65	40	55	55	55	55	59	50
	PT			10	30	45	45	45	10	30	40	50	40		
"	ASSR	awake	yes	15	40	55	50	45	0	35	55	60	45	60	55
	PT			20	40	45	50	40	5	15	35	40	30		
"	ASSR	awake	yes	0	45	40	25	40	0	15	40	25	30	61	70
						LEFT EAR					RIGHT EAR				
Machine	Test	Protocol	Sedation	500 Hz	1000 Hz	2000 Hz	3000 Hz	4000 Hz	500 Hz	1000 Hz	2000 Hz	3000 Hz	4000 Hz	Subject	Time
Biologic	PT			20	40	60	60	55	10	30	55	55	40		
	ASSR	Master	yes	30	40	60	.	60	25	50	.	.	.	62	130
	PT			35	40	55	55	75	25	40	35	40	65		
ditto	ASSR	Master	yes	30	30	30	.	75	10	45	30	.	55	63	99
	PT			20	40	45	55	50	10	35	40	45	55		
"	ASSR	Master	yes	30	50	40	.	55	30	40	50	.	60	64	80
	PT			15	50	50	45	50	20	45	50	45	55		

				LEFT EAR					RIGHT EAR						
Machine	Test	Protocol	Sedation	500 Hz	1000 Hz	2000 Hz	3000 Hz	4000 Hz	500 Hz	1000 Hz	2000 Hz	3000 Hz	4000 Hz	Subject	time
"	ASSR	Master	yes	45	45	45	.	45	45	45	45	.	55	65	85
	PT			15	25	75	75	75	10	25	55	45	45		
"	ASSR	Master	yes	20	.	75	.	.	30	50	.	.	.	66	129
	PT			20	55	50	60	60	25	50	55	60	60		
"	ASSR	Master	yes	20	40	40	.	60	30	50	50	.	50	67	85
	PT			15	40	45	40	40	25	40	45	45	50		
"	ASSR	Master	yes	30	40	40	.	.	50	50	40	.	50	68	90
	PT			25	45	45	50	35	30	45	45	50	45		
"	ASSR	Master	yes	35	45	45	.	35	.	45	50	.	45	69	80
	PT			0	25	40	50	60	5	20	35	50	65		
"	ASSR	Master	yes	10	30	50	.	75	20	30	50	.	75	70	85
	PT			15	20	40	30	25	15	25	45	40	40		
"	ASSR	Master	yes	10	20	20	.	40	20	30	30	.	40	71	80
	PT			30	40	40	40	50	25	35	55	65	60		
"	ASSR	Master	yes	30	40	40	.	60	50	40	60	.	60	72	90
	PT			25	40	35	35	40	30	40	40	35	40		
"	ASSR	Master	yes	30	35	30	.	40	35	40	35	.	50	73	85
	PT			30	40	50	50	60	25	30	50	55	65		
"	ASSR	Master	yes	40	40	50	.	50	40	40	45	.	50	74	114
	PT			20	45	55	50	50	20	45	45	45	55		
"	ASSR	Master	yes	40	50	60	.	.	50	50	60	.	.	75	80
	PT			15	40	50	50	50	20	40	45	40	50		
"	ASSR	Master	yes	10	40	40	.	40	10	40	45	.	50	76	70
	PT			30	30	35	55	50	20	50	60	55	65		
"	ASSR	Master	yes	10	20	40	.	50	40	40	60	.	60	77	66
	PT			20	40	45	30	30	20	45	35	35	20		
"	ASSR	Master	yes	25	45	25	.	35	20	50	25	.	20	78	70
	PT			30	40	45	40	45	30	40	45	40	45		
"	ASSR	Master	yes	40	40	30	.	45	40	40	40	.	40	79	145
	PT			10	35	55	45	35	10	25	40	40	45		
"	ASSR	Master	yes	25	35	55	.	.	25	15	45	.	.	80	72
	PT			30	60	50	50	45	35	60	55	50	50		
"	ASSR	Master	yes	40	50	50	.	50	50	50	50	.	60	81	75

APPENDIX O

RAW DATA: PSEUDOHYPACUSIC GROUP
PURE TONE AND ASSR THRESHOLDS (n=29)

				Left	Hz				Right	Hz				Subject	Time	Time
Machine	Test	Protocol	Sedation	500	1000	2000	3000	4000	500	1000	2000	3000	4000	no.	prep	test
Audera	PT 1	awake	no	75	75	90	95	90	50	70	65	85	85			
	PT2			.	.	.	.	.	.	.	.	.	.			
	Diagnostic			40	60	.	.	.	30	45	45	.	.			
	ASSR			10	15	25	.	20	0	30	15	.	30	1	8	60
Audera	PT1	awake	no	.	.	.	.	.	.	.	.	.	.			
	PT 2			95	95	90	95	90	95	95	95	95	95			
	Diagnostic			.	105	110	110	.	.	110	110	.	.			
	ASSR			.	.	.	.	.	65	80	65	.	70	2	8	62
Audera	PT 1	awake	no	.	.	.	.	.	.	.	.	.	.			
	PT 2			55	60	80	90	95	55	60	55	55	60			
	Diagnostic			65	65	80	95	90	50	50	50	50	60			
	ASSR			35	60	65	.	95	30	50	50	.	60	3	.	45
Biologic	PT 1	Master	yes	.	.	.	.	.	.	.	.	.	.			
	PT 2			70	75	90	90	95	90	95	95	95	95			
	Diagnostic			.	.	110	.	.	105	110	.	.	.			
	ASSR			25	30	30	.	40	15	30	40	.	40	4	.	55
Audera	PT 1	awake	yes	25	20	40	20	40	30	10	20	10	25			
	PT 2			40	55	55	50	55	5	10	20	10	35			
	Diagnostic			100	100	100	.	.	100	85	100	.	.			
	ASSR			30	35	50	60	55	15	10	25	40	30	5	7	32
Auders	PT 1	awake	yes	10	30	50	55	45	25	30	65	60	55			
	PT 2			.	.	.	.	.	.	.	.	.	.			
	Diagnostic			110	110	110	90	100	110	110	110	.	.			
	ASSR			0	30	50	50	45	0	30	55	35	60	6	.	75
Audera	PT 1	awake	yes	25	10	35	40	45	25	20	40	40	35			
	PT 2			40	40	60	60	90	40	50	60	60	100			
	Diagnostic			80	75	90	100	105	110	105	105	110	110			
	ASSR			0	30	40	45	50	10	20	70	70	30	7	.	45
Audera	PT 1	awake	yes	25	20	10	60	80	70	55	45	55	70			
	PT 2			80	80	100	0	0	0	0	0	0	0			
	Diagnostic			70	80	80	90	110	105	110	110	110	110			
	ASSR			55	55	55	100	100	55	85	110	105	110	8	.	53
Audera	PT 1	awake	yes	25	20	40	30	50	45	60	25	55	45			
	PT 2			50	90	95	95	95	90	95	95	90	100			
	Diagnostic			85	70	95	.	.	110	110	110	.	.			
	ASSR			0	10	20	15	50	30	25	50	50	80	9	.	46
Audera	PT 1	awake	yes	25	35	25	10	25	20	30	30	20	20			
	PT 2			45	60	70	60	70	60	70	70	65	70			
	Diagnostic			90	90	95	105	110	105	100	100	110	110			
	ASSR			.	.	.	.	.	15	35	25	35	30	10	.	62
Audera	PT 1	awake	yes	15	5	15	20	15	15	15	15	25	15			
	PT 2			50	60	65	85	90	40	20	40	25	30			
	Diagnostic			70	70	80	.	.	45	60	.	.	.			
	ASSR			50	70	90	100	120	15	25	20	.	.	11	.	73

				Left	Hz				Right	Hz				Subject	Time	Time
Machine	Test	Protocol	Sedation	500	1000	2000	3000	4000	500	1000	2000	3000	4000	no.	prep	test
Audera	PT 1	awake	yes	55	55	15	20	30	5	0	0	20	5			
	PT 2			70	55	20	35	35	10	10	5	25	10			
	Diagnostic			80	80	95	110	95	90	90	110	110	55			
	ASSR			65	75	70	80	80	15	25	55	70	70	12	.	77
Audera	PT 1	awake	yes	15	20	10	10	30	10	15	15	20	30			
	PT 2			50	70	65	65	85	45	60	65	70	80			
	Diagnostic			95	100	100	110	.	95	110	110	.	.			
	ASSR			10	40	55	70	80	15	35	75	75	80	13	.	73
Audera	PT 1	awake	yes	5	45	50	60	55	10	40	45	60	55			
	PT 2			25	55	55	65	70	20	55	55	70	60			
	Diagnostic			110	110	110	110	110	110	110	110	110	110			
	ASSR			30	60	65	65	60	40	50	60	75	80	14	8	45
Audera	PT 1	awake	yes	5	5	0	10	5	5	5	5	5	10			
	PT 2			20	30	25	55	60	30	20	15	50	60			
	Diagnostic			100	85	110	110	110	110	110	110	110	110			
	ASSR			10	25	40	45	.	0	30	20	35	.	15	.	42
Audera	PT 1	awake	yes	10	5	5	5	15	10	0	15	5	0			
	PT 2			25	70	75	70	70	40	65	75	70	75			
	Diagnostic			85	90	105	105	110	95	100	105	105	105			
	ASSR			105	90	110	110	110	0	60	55	45	55	16	.	40
Audera	PT 1	awake	yes	20	25	20	30	30	25	25	30	15	25			
	PT 2			20	25	35	20	20	70	75	80	80	75			
	Diagnostic			90	85	110	110	110	110	110	110	110	110			
	ASSR			15	35	50	45	30	60	60	55	35	.	17	10	64
Audera	PT 1	awake	yes	55	45	30	25	40	45	30	35	20	40			
	PT 2			85	75	70	70	70	70	70	75	70	80			
	Diagnostic			100	105	110	100	100	100	105	110	110	110			
	ASSR			40	35	50	35	55	30	25	35	45	80	18	.	51
Audera	PT 1	awake	yes	15	25	55	65	55	40	25	50	60	60			
	PT 2			10	25	55	65	60	15	25	50	60	55			
	Diagnostic			100	100	100	.	.	100	95	95	90	110			
	ASSR			40	35	60	60	55	15	30	60	60	55	19	7	30
Audera	PT 1	awake	yes	5	0	0	10	5	0	0	0	5	5			
	PT 2			20	15	10	20	20	70	90	90	90	95			
	Diagnostic			85	95	100	110	110	95	110	110	110	110			
	ASSR			10	10	25	30	30	5	10	20	20	30	20	10	45
Audera	PT 1	awake	yes	20	30	35	50	45	25	30	40	45	45			
	PT 2			45	45	50	60	65	55	55	60	70	70			
	Diagnostic			70	65	85	.	.	75	85	90	.	.			
	ASSR			0	35	50	60	55	40	55	85	95	110	21	8	50
Audera	PT 1	awake	yes	.	.	.	.	.	.	.	.	.				
	PT 2			.	.	.	.	.	.	.	.	.	.			
	Diagnostic			110	110	110	110	110	110	110	110	110	110			
	ASSR			40	60	70	70	80	40	60	70	70	80	22	10	26
Audera	PT 1	awake	yes	5	10	5	10	10	0	5	5	0	5			
	PT 2			90	95	95	95	95	95	95	95	95	95			
	Diagnostic			105	105	105	110	110	110	110	110	110	110			
	ASSR			0	25	20	35	20	0	5	20	35	30	23	10	48
Audera	PT 1	awake	yes	35	20	35	20	15	20	20	30	10	30			
	PT 2			25	45	40	40	40	85	70	95	95	85			
	Diagnostic			75	65	70	70	80	105	100	110	110	110			
	ASSR			0	30	65	65	55	110	100	110	110	110	24	10	35

				Left	Hz				Right	Hz				Subject	Time	Time
Machine	Test	Protocol	Sedation	500	1000	2000	3000	4000	500	1000	2000	3000	4000	no.	prep	test
Audera	PT 1	awake	yes	0	20	20	30	40	0	25	5	10	5			
	PT 2			35	40	35	65	45	25	40	25	45	30			
	Diagnostic			70	60	95	95	100	80	90	90	100	110			
	ASSR			30	40	60	60	55	30	50	50	70	70	25	9	37
Audera	PT 1	awake	yes	25	25	20	20	20	35	30	40	35	35			
	PT 2			10	15	10	5	20	60	60	70	80	80			
	Diagnostic			100	110	110	110	110	100	100	110	110	110			
	ASSR			0	20	25	45	45	0	10	40	45	45	26	7	55
Audera	PT 1	awake	yes	25	40	20	35	35	50	55	25	50	45			
	PT 2			80	90	90	85	85	70	85	80	95	85			
	Diagnostic			90	85	90	.	.	100	100	95	.	.			
	ASSR			60	90	85	75	70	40	70	60	75	85	27	5	55
Audera	PT 1	awake	yes	20	30	45	50	50	5	30	45	50	50			
	PT 2			25	45	60	60	60	25	50	60	65	65			
	Diagnostic			100	100	110	110	110	105	110	110	110	110			
	ASSR			5	50	50	60	45	0	50	60	60	50	28	5	32
Audera	PT 1	awake	yes	20	40	40	30	35	15	35	35	50	50			
	PT 2			55	65	70	70	85	60	65	70	75	85			
	Diagnostic			95	95	95	110	110	110	110	110	110	110			
	ASSR			0	35	25	60	50	30	50	60	40	50	29	7	33

APPENDIX P

ANALYSIS OF AVAILABLE DATA- PSEUDOHYPACUSIC GROUP

KEY:

A Pseudohypacusis proofed left
B Pseudohypacusis proofed right
C Normal hearing left ear
D Normal hearing right ear
E Abnormal exaggerated hearing left
F Abnormal exaggerated hearing right
G Case managed successfully
H Compensable
I within compensable range
J Fit
K Correlates with previous test left
L Correlates with previous test right
M Sudden deterioration left
N Sudden deterioration right
O Referred by Occupational Health centre/ENT

Subject no	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	yes	yes	yes	yes	no	no	yes	no	no	yes	no	no	no	no	OHC
2	no	yes	.	no	.	yes	no	.	yes	no	no	no	.	.	OHC
3	yes	yes	no	no	yes	yes	yes	yes	yes	yes	no	yes	.	no	OHC
4	yes	yes	no	no	yes	yes	yes	yes	yes	yes	no	no	.	.	OHC
5	yes	yes	no	no	yes	yes	yes	no	no	yes	yes	yes	no	no	ENT
6	yes	yes	no	no	yes	yes	yes	yes	yes	yes	yes	yes	no	no	OHC
7	yes	yes	no	no	yes	yes	yes	yes	yes	yes	yes	no	no	no	OHC
8	yes	yes	no	no	yes	yes	yes	yes	no	no	no	no	yes	yes	ENT
9	yes	yes	no	no	yes	yes	yes	no	no	yes	no	no	no	no	OHC
10	yes	yes	.	no	.	yes	yes	yes	yes	yes	.	yes	no	no	OHC
11	yes	yes	no	yes	yes	no	yes	no	no	yes	no	yes	yes	no	ENT
12	yes	yes	no	no	yes	yes	yes	no	yes	yes	no	no	yes	yes	ENT
13	yes	yes	no	no	yes	yes	yes	no	yes	yes	yes	yes	yes	yes	ENT

Subject no	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
14	yes	yes	no	no	yes	yes	yes	yes	yes	yes	yes	yes	no	no	OHC
15	yes	yes	no	yes	yes	no	yes	no	no	yes	yes	no	no	no	OHC
16	yes	yes	no	no	yes	yes	yes	no	yes	no	no	no	yes	yes	OHC
17	yes	yes	no	no	yes	yes	yes	no	yes	yes	yes	no	no	yes	ENT
18	yes	yes	no	no	yes	yes	yes	yes	yes	yes	no	no	no	no	OHC
19	yes	yes	no	no	yes	yes	yes	yes	yes	yes	yes	yes	no	no	ENT
20	yes	yes	yes	yes	no	no	yes	no	no	yes	yes	yes	no	no	ENT
21	yes	yes	no	no	yes	yes	yes	no	yes	yes	yes	no	no	yes	OHC
22	yes	yes	no	no	yes	yes	yes	yes	yes	no	.	.	.	.	OHC
23	yes	yes	yes	yes	no	no	yes	no	no	yes	yes	yes	no	no	OHC
24	yes	no	no	no	yes	yes	yes	yes	no	no	no	no	yes	yes	OHC
25	yes	yes	no	no	yes	yes	yes	no	yes	yes	yes	no	yes	yes	OHC
26	yes	yes	no	no	yes	yes	yes	no	no	yes	no	yes	yes	no	ENT
27	yes	yes	no	no	yes	yes	yes	no	yes	no	yes	no	yes	yes	OHC
28	yes	yes	no	no	yes	yes	yes	yes	yes	yes	yes	yes	no	no	OHC
29	yes	yes	no	no	yes	yes	yes	yes	yes	yes	no	no	no	no	OHC

APPENDIX Q

COSTING OF ASSR METHODS IN THE MINING INDUSTRY

”I feel that it would be difficult, if not impossible, to derive an accurate formula for estimating the financial impact of malingering (pseudohypacusis) in respect of noise-induced hearing loss in the mining industry.” (Begley, 2003)

Complicating factors that lead to this difficulty include the following:

- Production teams consist of 16 to 18 workers. If one worker is absent, the job still continues, making it difficult to quantify any production loss due to one individual’s absence.
- Groups of workers are transported to hospitals and clinics on a daily basis, and one or two additional cases per day may not have a significant impact.
- It is impossible to say how much overcompensation occurs or has occurred, as no objective measure or indicator has ever been put in place. Insurers contend that two separate diagnostic audiograms and assessment by the Occupational Health or Medical Practitioner, along with a review of each case by the insurer’s claims assessors should minimise false claims (Begley, 2003).

The present author and other audiologists consulting to the industry have noted an escalation of apparently erroneous compensation or overcompensation of pseudohypacusic individuals, particularly since the implementation of WCC Instruction 168 in 1995. Haugton *et al*. (1979) found that subjects were able to consistently feign or exaggerate hearing loss within 6 dB (nine per cent), well within the 10 db of variance needed to refute a compensation claim. In addition, Rickards and De Vidi (1995) found that individuals who had been compensated had exaggerated their hearing loss by 12, 2 per cent.

Taking into account the preceding points, the potential cost of pseudohypacusis has been analysed considering the following components:

- lost production;
- lost shifts;

- transport costs;
- specialist referrals;
- overcompensation;

1. LOST PRODUCTION

Lost production can be estimated is as follows (Geyser, 2003):

A 30-metre panel worked by a team of 16 workers carries a production cost of R 79 000 per day, indicating that a single worker's absence for one day amounts to R 4 937,50 in lost production. Admittedly, a drill operator's absence would have a more direct impact on production, but there are very few instances of stope teams being over-complemented and, hence, the overall average is calculated across the entire team.

2. LOST SHIFTS

A rock drill operator, normally classified as Category 4, earns an average monthly wage of R 2 260 per month, or R 113 per day.

3. TRANSPORT COSTS

Transporting workers to Occupational Health Centres, hospitals and clinics costs R 70 000 per month for a single region in one mining group (Geyser, 2003). The average number of workers transported each month is 584, implying a cost of R 120,68 per worker.

4. SPECIALIST REFERRALS

Various scenarios are possible in cases of pseudohypacusis, as follows:

4.1 Second referral for audiology

A worker may be referred for re-evaluation by the audiologist where thresholds have not been obtained. The cost can be calculated as follows:

Lost shift	**R 113,00**
Lost production	**R4 937,50**
Transport	**R 120,68**
Audiology:	
Consultation	R 82,30
Air-conduction audiometry	R 37,20
Bone-conduction audiometry	R 37,20
Tympanometry	R 37,20
Acoustic reflexes	R 37,20
Cost of audiology:	**R 231,10**
Total cost of audiologist referral:	**R5 402,28**

4.2 ENT referral

If the audiologist's second attempt to determine thresholds is unsuccessful, the worker is often referred to an ENT specialist.

Lost shift	**R 113,00**
Lost production	**R4 937,50**
Transport	**R 120,68**
Consultation	**R 113,40**

The ENT will be unable to finalise the diagnosis without a reliable audiogram, and it may be necessary to repeat audiological procedures.

Air-conduction audiometry	R 37,20
Bone-conduction audiometry	R 37,20
Tympanometry	R 37,20
Acoustic reflexes	R 37,20
Cost of audiology:	**R 231,10**
Total cost of ENT referral:	**R5 515,68**

4.3 ABR testing

If the ENT is still unable to make a final diagnosis and determine hearing thresholds, an ABR may be requested.

Lost shift	**R 113,00**
Lost production	**R4 937,50**
Transport:	**R 120,68**
ABR testing	**R 503,36**
Revisit ENT	**R 113,40**
Total cost of ABR assessment:	**R5 787,94**

These costs indicate that without considering the effect of any overcompensation, the cost of assessing a pseudohypacusic worker can amount to between R 5 402,28 and

R 16 705,90. After all these costs have been incurred, it often happens that pure-tone thresholds have still not been determined across the frequency range and thus the case remains unresolved.

A total of 2 526 diagnostic evaluations were performed for employees in one region of a single mining group during the past financial year (Geyser, 2003). If only 10 per cent of these involved pseudohypacusis (a very conservative estimate), it implies that 253 workers cost the employer R 1,367M in unnecessary diagnostic evaluations, assuming that each one required only one day off work and that no ABR testing or ENT referrals were involved.

In this light, the R 154 000 cost for an ASSR test system (HASS, December 2003) would be recovered in a matter of months, and the instrument would not need replacement for at least five years. In addition, ASSR testing would enable the diagnosis and evaluation of noise-induced hearing loss cases to be finalised more quickly, serving the interests of both the employer and deserving workers.

4.4 Overcompensation

The literature indicates that between 9 and 33 per cent of workers who face the prospect of claiming compensation exaggerate their hearing losses. Haughton *et al*. (1979) shown that it is possible to consistently exaggerate a hearing loss within six dB (nine per cent), which should be compared with the 10 dB of variance needed to refute a test as unreliable. It is quite possible for an audiologist to overlook this amount of exaggeration.

The average compensation settlement for noise-induced hearing loss among 228 workers at one regional operation of a single mining group was approximately R 12 000 during the past financial year (Geyser, 2003). If only 10 per cent of these claimants exaggerated their hearing loss by 6 dB (a discrepancy which would be taken as a reliable reading), this would amount to a total overcompensation of R 184 000 (R 8 000 per worker x 23 workers). This is based on the following:

A worker with earnings of R 4000 per month (including salary, overtime, holiday allowance and housing) is compensated by an amount of R 12 000 for a permanent disability (PD) of 6 per cent.

This amount is based on

Earnings multiplied by percentage of PD, multiplied by 15 and divided by 30, i.e.

R 4 000 x 6 x 15 ÷ 30 = R 12 000.

If this worker has exaggerated his hearing loss by 9 per cent, his percentage PD would have risen to 10 per cent, with the following effect:

R 4 000 x 10 x 15 ÷ 30 = R 20 000, i.e. an overcompensation of R 8 000.

This is a simplistic way of evaluating the possible financial impact of overcompensation, since claimants earn different salaries, and have varying levels of hearing loss and, hence, percentages permanent disability. Nevertheless, this exercise demonstrates that the use of truly objective methods for assessing noise-induced hearing loss in pseudohypacusic workers would yield considerable cost savings.

APPENDIX R

PROOF OF LANGUAGE EDITING: I NOOMÉ

14 May 2004

TO WHOM IT MAY CONCERN

This is to certify that I have language edited the whole thesis by Elize de Koker on hard copy on the understanding that she would make the language changes required on the electronic version. The last three chapters were edited electronically, using the 'track changes' facility in MS WORD to enable her to accept or reject changes and respond to editorial queries.

Yours faithfully

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