

Safety in Mines Research Advisory Committee.

Final report on

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Part 1.

Evaluate the viability of auditory steady state response testing for pseudohypacusic workers in the South African mining industry.

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Executive summary.

Large numbers of South African mineworkers incur noise-induced hearing loss (NIHL), which is recognised as a compensable disease by COIDA (Compensation for Occupational Injuries and Diseases, 1993 (Act 130 of 1993)). The prevalence of NIHL is such that its financial implications for the industry are substantial, threatening the viability of marginal operations and eroding the profitability of others. Of even greater concern is the impact on workers' quality of life.

With regard to NIHL's financial impact, this is compounded by an exaggeration of hearing loss on the part of some workers (pseudohypacusis) in an attempt to obtain compensation. In a review of the literature, it was found that the highest prevalence of pseudohypacusis (exaggerated or simulated hearing loss) has been reported among workers eligible for monetary compensation in the event of NIHL. In the South African mining industry, the occurrence of noise-induced hearing loss and compensation are well documented. Franz (2001) found that audiologists consulting to mines' Occupational Health Departments frequently cited pseudohypacusis as the greatest impediment to assessing the true hearing status of patients referred to them. During a three-month period, the researcher found clear indications of pseudohypacusis in 32 per cent of 160 cases referred for audiological assessment. Such cases must be re-assessed several times by the consulting audiologist and Ear, nose and throat specialist, increasing the cost of evaluations and the number of unproductive shifts, and impacting on the effectiveness of Audiology- and Occupational Health Departments.

Difficulties in determining true hearing thresholds may also result in warranted compensation claims not being settled, failure to identify instances of sudden hearing loss, and unfit (in terms of hearing) employees being returned to work, further exposing them and increasing the risks to the individual and fellow workers. Current audiological procedures can identify instances of exaggerated hearing loss (pseudohypacusis), but it is difficult to quantify the extent of the exaggeration. Hearing evaluations mainly employ pure-tone and speech discrimination techniques, in accordance with Workmen's Compensation Commissioner Instruction No 171 (2000). Although pure tone hearing tests are internationally regarded as the "gold standard" for hearing threshold determination, these methods require client cooperation and, hence, are inadequate to resolve cases where the individual deliberately seeks to feign or exaggerate hearing loss.

Accordingly, the present study was undertaken to evaluate auditory steady state response (ASSR) testing, as a means of accurately estimating the true hearing thresholds for pseudohypacusic mineworkers who may have NIHL, even without their active cooperation. An exploratory study was conducted to assess various test protocols and instruments for a normative group of subjects with noise-induced hearing loss, after which a selected protocol was evaluated for an experimental group of workers displaying pseudohypacusis.

The findings demonstrate the validity, sensitivity and accuracy of ASSR testing, particularly the single-frequency (SF) method, thereby providing a basis for the recommendation that SF-ASSR tests be implemented as an alternative to pure-tone testing for pseudohypacusic workers with noise-induced hearing loss. This method, using the 40 Hz response, was shown to estimate thresholds to within 10 dB of corresponding pure-tone results across the entire range of severity (normal hearing to profound hearing loss), and independent of the age of the individual. Furthermore, the use of automated testing and analysis algorithms with this method eliminates any possible influence from the clinician, thereby ensuring objectivity.

The use of sedation, as routinely used in evoked potential audiometry, was investigated to determine if sensitivity could be improved by reducing noise from subject movement and spontaneous EEG activity. It was found that sedation has no significant positive or negative effect on either aspect and, accordingly, its use is not recommended. Testing took an average of 60 minutes, considerably longer than conventional methods, but (unlike the latter) with the benefit of providing accurate threshold estimates and at one sitting. The procedure also estimated 10 thresholds in the 60 minutes, where auditory brainstem response testing (the current auditory evoked potential used) estimates only two thresholds in the same time.

The cost of implementation was evaluated against potential savings from reductions in lost shifts and production, unnecessary referrals and overcompensation of NIHL. Indications are that the cost of instrumentation (minimum service life of five years) could be recovered in a matter of months.

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Contents	Page
Executive summary.....	2
Acknowledgements	4
Contents	5
List of figures	7
List of tables.....	8
Abbreviations and nomenclature.....	9
1 Introduction	11
1.1 Noise-induced hearing loss and pseudohypacusis in the South African mining industry.....	11
1.2 Detection of pseudohypacusis	13
1.2.1 Reason for referral.....	13
1.2.2 Case history.....	14
1.2.3 Pure tone audiometry.....	14
1.2.4 Speech testing.....	16
1.2.5 Special tests	16
1.2.6 Electrophysiological tests	17
1.2.6.1 Immittance.....	18
1.2.6.2 Oto-acoustic emissions	19
1.2.6.3 Auditory evoked potentials	19
ABR.....	20
Slow vertical responses (SVR).....	20
Auditory steady state responses	21
1.3 Aims of the research.....	23
2 Methods	24
2.1 Research design	24
2.2 Subjects.....	25
2.2.1 Population	25
2.2.2 Sample selection	26
2.2.3 Employer permission and ethics approval	26
2.3 Testing procedures and equipment	27
2.3.1 Pure tone audiometry.....	27
2.3.2 Case history.....	27
2.3.3 Otoscopic examination	27
2.3.4 Tympanometry.....	28
2.3.5 Pseudohypacusis	28
2.4 Data collection equipment and procedures	28

2.4.1	Pure tone testing	29
2.4.2	MF-ASSR testing.....	29
2.4.3	SF-ASSR testing	32
2.5	Data collection equipment and procedures	38
3	Results and discussion.....	38
3.1	Age distribution of subjects-normative group	38
3.2	Exposure of subjects-normative group	41
3.3	Age distribution of pseudohypacusic group.....	44
3.4	Noise exposure of pseudohypacusic group.....	44
3.5	Clinical value of ASSR tests	45
3.6	Effectiveness of MF-and SF-methods for estimating thresholds in a NIHL population	50
3.7	Effect of stimulation rate.....	53
3.8	The effect of sedation on SF- and MF-results	54
3.9	ASSR testing of pseudohypacusic mineworkers.....	56
3.9.1	Revision of procedures for experimental group	56
3.9.2	Clinical value of ASSRs.....	56
3.10	Further analysis of findings	57
3.11	The time required for ASSR testing	58
3.12	Costing	58
4	Conclusions and recommendations.....	62
	References	67
	Appendix A: Case History	77

List of figures

Figure 2.4.3a	Electrode placement with Audera	34
Figure 2.4.3b	Phase locked response.....	35
Figure 2.4.3c	Random response.....	36
Figure 2.4.3d	Example of results rejected due to excessive noise.....	36
Figure 2.4.3e	Plotted results of trials during an ASSR test.....	37
Figure 2.4.3f	Estimated pure tone audiogram based on ASSR results	37
Figure 3.5a	Number of subjects with normal pure tone thresholds (25 dB and lower) for given ear and test frequency.....	45
Figure 3.5b	ASSR thresholds not obtained.....	49
Figure 3.1a	Age distribution of the SF/80 Hz/ non-sedated group	39
Figure 3.1b	Age distribution of the SF/40Hz/ non-sedated group.....	39
Figure 3.1c	Age distribution of the MF/80Hz/ non-sedated group.....	40
Figure 3.1d	Age distribution of the SF/40Hz/sedated group.....	40
Figure 3.1e	Age distribution of MF/80Hz/sedated group.....	41
Figure 3.2a	Experience/exposure : SF/80Hz/non-sedated group.....	41
Figure 3.2b	Experience/exposure : SF/40Hz/ non-sedated group	42
Figure 3.2c	Experience exposure: Biologic/MF/non-sedated group.....	42
Figure 3.2d	Experience/exposure: SF/40Hz/sedated group.....	43
Figure 3.2e	Experience/exposure: MF /sedated group	43
Figure 3.3	Age distribution of pseudohypacusic group.....	44
Figure 3.4	Experience/exposure: Pseudohypacusic group	44

List of tables

Table 2.1	Research design of present study	24
Table 2.4.2	Modulation frequencies used by MASTER	31
Table 3.5a	Sensitivity of ASSR-and pure-tone testing by test frequency.....	46
Table 3.5b	Comparison of pure-tone and ASSR results for left and right ears.....	47
Table 3.5c	Mean difference between ASSR estimated and pure tone thresholds	47
Table 3.6a	Average number of frequencies completed with SF- and MF testing	50
Table 3.6b	Time taken for SF- and MF-tests independent of number of frequencies completed	51
Table 3.6c	Time taken for SF- and MF-tests normalized for number of frequencies completed.....	51
Table 3.6d	Differences in sensitivity between SF- and MF- stimulation techniques	53
Table 3.8a	Significance of differences in MF- and SF-test time with and without sedation	54
Table 3.8b	Significance of sensitivity differences in SF-ASSR testing for sedated and non-sedated subjects	54
Table 3.8c	Significance of sensitivity differences in MF-ASSR tests for sedated and non-sedated subjects	55

Abbreviations and nomenclature

ABR	auditory brainstem response
AEP	auditory evoked potential
AM	amplitude modulated
AR	acoustic reflex
ASSR	auditory steady state response
AIDS	acquired immune deficiency syndrome
CER	cortical evoked responses
CF	carrier frequency
dB	decibel
EAM	external auditory meatus
EEG	electro encephalogram
EP	electro-physiological tests
ERP	event related potential
f	frequency
FM	frequency modulation
FFT	fast fourier transform
HIV	human immunodeficiency virus
HL	hearing level
HTL	hearing threshold level
Hz	Hertz
kHz	kilohertz
L	left
MASTER	multiple auditory steady state response system
MF	multi frequency
MF ASSR	multi frequency auditory steady state response
mg	milligram
MOHAC	mines occupational health advisory committee
NIHL	noise-induced hearing loss
OAE	oto-acoustic emission
OHC	occupational health centre
OMP	occupational medical practitioner
PD	permanent disability
Ps	pseudohypacusis
PT	pure tone
PTA	pure tone average
R	right
RSA	Republic of South Africa
SF	Single frequency
SF-ASSR	single frequency auditory steady state response
SNHL	sensory-neural hearing loss

SPAR sensitivity prediction with the acoustic reflex
SPONDEE two syllabic word with equal accent on both syllables
SRT speech reception threshold
SSEP steady state evoked potential;
SVR slow vertical response

1 Introduction

1.1 Noise-induced hearing loss and pseudohypacusis in the South African mining industry.

Large numbers of South African mineworkers incur noise-induced hearing loss (NIHL), which is recognised as a compensable disease by COIDA (Compensation for Occupational Injuries and Diseases, 1993). The prevalence of NIHL is such that its financial implications for the industry are substantial, threatening the viability of marginal operations and eroding the profitability of others. Of even greater concern is the impact on workers' quality of life and their ability to earn a living, which has socio-economic implications for the entire country and the Southern African region. With regard to the financial impact of NIHL, this is often compounded by exaggeration of hearing loss (pseudohypacusis) on the part of some workers in an attempt to obtain compensation.

Most adults examined by audiologists for complaints of hearing loss have genuine disorders of the auditory system, for which the audiologist must establish the type and extent of hearing loss to determine the most appropriate course of action. This may involve rehabilitation, re-allocation or, in extreme cases, compensation and/ or termination from the current occupation.

Unfortunately, for various reasons, some workers are not entirely cooperative during audiological procedures. These include misunderstanding of test procedures or their purpose, physical or psychological disorders, or an intention to misrepresent their hearing thresholds (Martin 1994). Qiu, Stucker, Shengguang and Welsh (1998) are of the opinion that such lack of cooperation can be unconscious (psychogenic) or deliberate (malingering). The term "pseudohypacusis" is applied in cases of malingering, i.e. *pseudo*, false/less-than-true, and *hypacusis*, hearing loss (Rintelmann *et al* 1991).

In a review of the literature, Rintelmann *et al* (1991) indicated that the highest prevalence of pseudohypacusis has been reported among adult populations in which hearing loss can result in monetary compensation. In the South African mining industry the occurrence of noise-induced hearing loss and resultant compensation are well documented, and it is widely known that their prevalence is greater in mining than in most other industries, largely due to the use of noisy machinery in confined and highly reverberant underground

workplaces (Franz and Phillips 2001). The labour-intensive methods used in many South African mines, particularly conventional gold and platinum operations where workforces are large, greatly increase the risk of NIHL (Franz and Phillips 2001).

The mining industry's recent experience with NIHL compensation is that between 12 and 14 per cent of claims for all forms of disease and injury have been for NIHL, but that these have accounted for nearly 40 per cent of the monies paid out (Begley 2002). NIHL claims settled by Rand Mutual Assurance, the underwriters of compensable risks for nearly four-fifths of the local mining workforce, have ranged between R 76m and R 110m since 1998. If it is assumed that claims from the 22 per cent of mineworkers who are otherwise insured (e.g. by the Workmen's Compensation Commissioner) are proportionally similar, settlements for NIHL industry-wide can be calculated at between R 98m and R 142m over the same period. These amounts are undeniably substantial and include neither the costs of repeat assessments, specialist referrals and transport arrangements, nor time off work and lost production. This indicates that NIHL risks imposes a significant burden on individual mining operations and on the entire industry, threatening sustainability and creating the potential for socio-economic impacts that a developing country can ill afford.

Thousands of workers have incurred NIHL and are therefore entitled to compensation. However, the experience of audiologists working in the mining industry is that significant numbers of claimants exaggerate their existing hearing loss, in an attempt to qualify for compensation or increase their settlement amount.

Franz and Phillips (2001) state that audiologists consulting to mines' Occupational Health Departments cite malingering or pseudohypacusis as the greatest impediment to assessing the true hearing status of patients referred to them. During a three-month period, this author found clear indications of pseudohypacusis in 32 per cent of 160 cases referred for audiological assessment. Diagnosis of pseudohypacusis was based on a discrepancy of more than 15 dB between thresholds recorded during two pure-tone tests, in accordance with the criterion proposed by Rintelmann *et al* (1991).

Evidence from multiple sources indicates a dire need for a reliable means not only to identify pseudohypacusis, but also to ensure accurate recording of noise-exposed

workers' hearing thresholds. Rickards, de Vidi and McMahon (1998) examined the financial impact of pseudohypacusis, citing Australian studies that reported 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, and concluded that undetected exaggeration of hearing loss can lead to substantial increases in compensation payouts and, hence, employers' costs for insuring NIHL risks. Rickards and de Vidi (1995) estimated that overcompensation by an average amount of A\$ 7 357 is awarded to workers with exaggerated hearing loss, amounting to A\$ 12m per year in Australia. The South African mining industry, with its much larger workforce, can ill-afford such a waste of financial resources.

Pseudohypacusis has further financial impact, in that current audiological procedures rely on workers' cooperation to determine hearing thresholds. Consequently, questionable cases must be re-assessed several times by the consulting audiologist and Ear, nose and throat specialist increasing the cost of evaluations and the number of unproductive shifts. Diagnostic hearing evaluations mainly employ pure-tone air- and bone-techniques and speech discrimination testing, in accordance with Workmen's Compensation Commissioner Internal Instruction No 168 (1995) (subsequently replaced by Instruction No 171). These techniques, although internationally regarded as the "gold standard" for threshold determination, require patient cooperation and, hence, are inadequate to resolve cases where patient cooperation is not forthcoming.

1.2 Detection of pseudohypacusis

Current audiological test methods and existing knowledge contribute to the detection of pseudohypacusis. Some of the indicators follow:

1.2.1 Reason for referral

In many cases the reason for the referral will, in itself, suggest the possibility of pseudohypacusis (Qiu *et al.* 1998), e.g. when a patient is referred in order to investigate or evaluate a compensation claim. This is a common occurrence in the mining industry.

1.2.2 Case History

A case history, taken by the audiologist before a hearing test, aids in the detection of pseudohypacusis. The patient's body language can feign reliance on lip-reading, and he may also ask the interviewer to repeat questions or instructions. The author's experience is that pseudohypacusic patients very often claim to suffer from symptoms associated with hearing loss, and they tend to exaggerate these symptoms.

1.2.3 Pure-tone audiometry

Qiu *et al.* (1998) stated that it is not difficult for the audiologist to detect pseudohypacusis using conventional audiological procedures. This may be true in the case of an experienced audiologist, but it is the author's opinion that inexperienced audiologists often fail to scrutinise patients' behaviour and other indicators of underlying intentions, thereby misdiagnosing the nature of the hearing loss. In addition, current methods require considerable time and effort to evaluate pseudohypacusic cases, and results are often inconclusive.

Rintelmann *et al* (1991) states the best indicator of pseudohypacusis is inconsistent test responses. Where two threshold determinations for the same frequency differ by more than 10 dB, the results are treated as inconclusive. The current practice of performing two pure-tone tests for potential compensation cases allows the identification of possible pseudohypacusis before any further testing is done. Repeating the test with an intervening time lapse is intended to confound any attempt to consistently exaggerate a hearing loss. However, Haughton, Lewsley, Wilson and Williams (1979) 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 six dB, on average. This raises the concern that self-discipline and familiarity with the test procedure could enable workers to consistently feign a hearing loss and falsely qualify for compensation or inflate settlements.

Rintelmann *et al* (1991) recommend a procedure that, in the author's experience, may be the most effective and time-efficient method for detecting pseudohypacusis. The recommendation is for two pure-tone air-conduction tests, using different presentation methods. Patients attempting 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). When applied to pseudohypacusic patients, this procedure generally demonstrates significant

discrepancies between the two pure tone tests, thereby identifying the patient as pseudohypacusic.

Another indication of pseudohypacusis using pure-tone audiometry is the shape of the audiometric curve. A flat configuration is very often an indication of pseudohypacusis (Martin 1994). Discrepancies between the audiometric results and the patient's social function should also alert the clinician to the possibility of pseudohypacusis. It is impossible for a patient with profound bilateral hearing loss to appropriately respond to questions or instructions presented at a normal conversational level of 50-60 dB, particularly if any attempt to read lips is subverted.

When a patient with a severe unilateral hearing loss is tested, the patient should hear a loud tone presented to the weak ear with the other ear, as result of the sound being conducted through the bones of the skull. A tone presented at a very high intensity may even leak past the earphone cushions and reach the better ear via air-conduction. The naïve pseudohypacusic patient indicates no hearing in one ear and good hearing in the other, which is impossible (Martin 1994), given the preceding discussion of interaural attenuation.

Qiu *et al.* (1998) discuss the common lack of correlation between bone- and air-conduction results among pseudohypacusic subjects. It is impossible for bone-conduction results to indicate worse hearing than air-conduction results, and a false air-bone gap is also discussed. This author's experience is that when the air-bone gap cannot be verified by otoscopic examination, medical history or, most importantly, the results of immittance testing, pseudohypacusis should be suspected.

Martin (1994) identifies two types of error in the determination of pure-tone thresholds, viz. 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. Extremely slow and deliberate responses, according to the same author, are indicative of pseudohypacusis, because most people respond immediately to test signals. Experience of the author supports the contention that the audiologist should suspect pseudohypacusis in cases of slow patient response.

Gold *et al.* (1991) state that exaggerated body movements and facial expressions (e.g. sitting on the edge of the chair and grimacing as to suggest extreme concentration) should be regarded as a sign of pseudohypacusis. This author has frequently observed such

behaviour, including exaggerated arm and hand movements while pressing the response button.

1.2.4 Speech testing.

Rintelmann *et al* (1991) suggest that threshold tests (air- and bone-conduction) be performed before immittance and speech discrimination tests, to prevent the patient from finding an above-threshold reference level.

Discrepancies between speech reception thresholds (SRT) and pure-tone average thresholds (PTA) also indicate pseudohypacusis. Gold *et al.* (1991) regard a difference of 15 dB between PTA and SRT (with PTA being the greater) as an indication of pseudohypacusis. These two parameters generally correspond very closely, and any discrepancy in the absence of a reasonable explanation (e.g. slope of the audiogram or poor word discrimination) is indicative of pseudohypacusis (Martin 1994).

Gold *et al.* (1991) reported pseudohypacusis patients with good speech discrimination scores at levels equalling or slightly exceeding admitted pure-tone thresholds. One hundred per cent discrimination is usually achieved only at a sensation level of 30 to 40 dB. The same authors also noted that pseudohypacusis patients often responded to spondee words by repeating only half of the word, e.g. "dog" for "hotdog".

Since SRT constitutes a threshold determination test, this should be the first step in a patient's evaluation, and the pure-tone testing should follow. Furthermore, mineworkers are very familiar with pure-tone air-conduction procedures as a result of annual screening, but most have had no exposure to speech audiometry.

1.2.5 Special tests.

A review of the literature indicated that several specialised tests have been developed to detect pseudohypacusis, including:

- ? Stenger test.(Chaicklin and Ventry 1965)
- ? Automatic audiometry (Jerger 1960)
- ? Delayed auditory feedback (Martin 1994)
- ? Swinging story test (Martin 1994)
- ? Pulse-count methods (Ross 1964)
- ? Yes-no test (Frank 1976)
- ? Doerfler-Stewart test (Doerfler and Stewart 1946)

- ? Lombard test (Simonton 1965)
- ? Sensorineural acuity level test
- ? Forced choice procedure (Haugton, Lewsley, Wilson, Williams 1979)
- ? Electrodermal audiometry (Gold 1991)

These tests are rarely used in current clinical practice, as they involve long and complicated procedures, require special equipment and, most importantly, cannot determine true hearing thresholds. In a clinical situation, particularly in the mining industry with large numbers of workers imposing large caseloads, there is little value to be gained from tests that confirm the detection of pseudohypacusis without establishing true hearing thresholds.

Accurate and objective information on hearing thresholds is crucial to the evaluation of compensation claims and determining workers' fitness. This need, along with the high incidence of pseudohypacusis among noise-exposed workers, has led many audiologists to employ electrophysiological procedures for estimating true hearing thresholds. However, Martin (1994) concluded that the “ *move to electrophysiological measures was not without disappointment*”.

1.2.6 Electrophysiological tests.

Audiologists have in the past always resorted to a test battery approach (Hall, 1998) to ensure reliable service delivery to their clients. Different tests in the repertoire of the audiologist ensured the possibility of a cross-check principle. Unfortunately in the endeavour to find accurate hearing thresholds, most of the other available tests have only confirmed the notion of pseudohypacusis and have not aided in getting the sought after frequency – specific threshold information.

Schmulian (2002) stated that the strongest cross-check principle is provided by measures that require no voluntary response from the patient while Gorga (1999) was also of the opinion that a pseudohypacusis population would need measures that did not rely on behavioural responses.

The quest for test procedures where behavioural responses are not required, has led to the development of electrophysiological tests (EP) to provide an objective assessment of auditory sensitivity (Hall, 1992). Schmulian (2002) also promoted physiological tests as

the answer to difficult-to-test populations since physiological tests countered the inherent flaws in human response.

De Waal (2000) mentioned that discoveries not only in the field of audiology, but also in other fields (e.g. neurology) have led to recent phenomenal advances especially in the area of electrophysiological tests. Swanepoel (2001) drew readers' attention to how closely the development of electrophysiological tests has followed advances in electrical technology. Developments in the field of EP tests during the past thirty years include immittance testing, acoustic reflex (AR) measurements, oto-acoustic emissions (OAEs) and auditory evoked potentials (AEPs).

Of the many electrical responses to auditory stimuli, most arise in the central nervous system. Some are generated in the cochlea (OAEs) and still others are reflex responses in muscles (immittance) (Glasscock, Jackson and Josey 1987).

1.2.6.1 Immittance.

The acoustic reflex (AR) is the most useful immittance measurement in the diagnosis of pseudohypacusis (Martin 1994). The same author suggests that if the difference between a reflex- and voluntary threshold is extremely low (5 dB or less), the pure-tone threshold must be questioned on the basis of organic pathology. 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 NIHL.

Tympanometry provides an immediate evaluation of middle ear status, as the AR and normal middle ear function cannot coincide with a conductive hearing loss (Qiu *et al.* 1998).

Acoustic reflex measurements may be useful in estimating actual hearing thresholds, by performance of the SPAR test. 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) claims that the sophistication of automated middle ear tests may discourage pseudohypacusis and that it is generally good practice to perform an immittance test first, telling the patient that the test reveals a great deal of information about his hearing status. This is a valid argument, but contradicts the earlier recommendation of Rintelmann *et al.* (1991) for supra-threshold tests to be performed after air- and bone-conduction tests.

1.2.6.2 Oto-acoustic emissions

Qui *et al.* (1998) state that it is impossible for a patient with hearing loss to have normal OAEs and, thus, advocates OAE testing as a quick and objective means of confirming hearing status in suspected cases of pseudohypacusis. 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 (De Koker *et al.* 2002).

1.2.6.3 Auditory evoked potentials

Hood (1998) emphasized the fact that EP tests were not tests of hearing but rather a test 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 electrophysiological thresholds obtained in AEP testing and behavioural thresholds approximated each other (Swanepoel 2001: Schmulian 2002: Rance *et al.* 1998: Reneau and Hnatiow 1975).

Spontaneous CNS or brain electrical activity can be recorded from the human scalp. This activity is routinely recorded in the electro-encephalogram (EEG) (Abranovich, 1990). This electrical activity can be spontaneous or event-related (Picton 2001). Responses that are time-locked to some event are called event-related potentials (ERPs). This event may be a sensory stimulus (such as a visual flash or a sound), a mental event or the omission of a stimulus (such as an increased time gap between stimuli) (Picton 2001).

Auditory evoked potentials (AEPs) are a subclass of ERPs where the event is a sound. AEPs are very small voltage potentials originating from the nervous system and recorded from the scalp in response to auditory stimuli such as different tones or speech sounds (Picton 2001). The AEPs recorded from the head originate from structures such as the auditory cortex, the auditory brainstem and the auditory or eighth cranial nerve. The electrical potentials are very low in voltage. Two to 10 micro volts for cortical AEPs and much less than one microvolt from deeper brainstem structures (Picton 2001).

Abranovich (1990) linked the use of AEPs to measurement of hearing in patients who can not or will not cooperate during behavioural tests. Schmulian (2002) took this above argument further in saying that in some patients, AEPs are the only procedure that can quantify the hearing sensitivity as a single test in a battery.

As a single test in a battery, AEPs should be able to meet the criteria of identifying:

- ? the nature of the hearing loss (conductive v. sensory-neural).
- ? the degree of hearing loss (normal hearing to profound hearing loss).
- ? the configuration of the hearing loss - thus all frequencies in the human range should be tested (250-8000 Hz).
- ? thresholds in both ears.

ABR

ABR, the most popular AEP, was described in the early 1970s. Jewett and Wiliston had established a definite description of the ABR in 1971 (Glasscock *et al* 1987). ABR has been the only electrophysiological procedure used in South Africa in the evaluation of difficult-to-test mineworkers.

Qiu *et al* (1998) confirmed that the ABR test provides a reliable method of estimating auditory sensitivity that cannot be evaluated by behavioural testing, but also mentioned the disadvantages of this method. The ABR is generated by sub-cortical structures only and thus can never be a true hearing test and ABR threshold estimates for clicks usually underestimate low-frequency hearing sensitivity. An ABR does supply the audiologist with audiometric thresholds but mainly in the 2000-4000 Hz field.

The ABR test, being an electrophysiological procedure, requires only passive cooperation from the patient, and can thus be used to confirm a suspicion of pseudohypacusis. However, the test's inability to provide frequency-specific information (required for compensation assessment) represents a significant limitation in terms of clear threshold determination.

Slow vertical responses (SVR)

Abranovich (1990) directed attention to the use of SVRs in stating that SVRs were the test of choice with a difficult- to-test population since it was the nearest to conventional testing although high levels of EEG activity made it difficult to detect SVRs in five per cent of cases .He claimed that SVR thresholds were within 10dB of pure tone thresholds. A definite problem with the accuracy of SVR testing is the technical experience and judgement of the audiologist. Abranovich (1990) and Rickards and de Vidi (1995) state that cortical evoked responses (CER) testing have been in use for pseudohypacusic NIHL

cases since 1975 in Australia. Rickards, *et al* (1996) reported that 18 per cent of all NIHL claimants in Victoria were referred for CER testing.

In spite of several recommendations for the use of CER tests in NIHL assessments, the acceptance of these techniques has not been universal. Rickards *et al* (1996) attributed this fact to the reliance on subjective interpretation of response tracings during the test and the high level of skill and training that is required of the clinician.

Auditory steady state responses

In the search for a true objective hearing test to use in a difficult-to-test population the focus has been on auditory evoked potentials (Rickards *et al* 1994) as can be seen in the preceeding review of the literature. Aoyagi *et al* (1994) were of the opinion that the ultimate goal of objective audiometry is to obtain an audiogram in a frequency-specific manner without a response from the subject. One aspect lacking objectivity in the above mentioned AEP tests of SVRs and ABRs was the clinician's perception, experience and skill that played a role in the detection of the appropriate waveforms elicited during AEP testing. Subjectivity was therefore still present in the decision of whether an evoked potential was present or not.

Rance, Rickards, Cohen, de Vidi and Clark (1995) alerted audiologists to the fact that ASSRs could be automatically detected by real-time statistical analysis of samples of the response phase with the use of a digital computer. With this final component of objectivity addressed, it left the possibility that electrophysiologic measures could now be the solution to assessing patients who cannot or will not participate actively in standard hearing procedures (Sininger and Cone – Wesson 1994).

Auditory steady state responses are potentially a solution to estimating frequency-specific and accurate hearing thresholds in a pseudohypacusic population without relying on the subjective detection of responses by the clinician.

Auditory steady state responses and steady state evoked potential (SSEP) are the two most frequently used acronyms found in a survey of relevant literature to describe this "new" AEP. Steady state fields (Pantev *et al* 1996), frequency following response (Kuwada *et al* 1986) and envelope following response (Dolphin and Mountain 1993) were other less frequently used acronyms. The terms ASSR and SSEP are used interchangeably. Nevertheless, Sininger and Cone-Wesson (1994) concluded that the term ASSR has become the term of choice in the past few years.

This AEP technique called ASSR was discovered and developed by the University of Melbourne in the 1980s (Era system, Pty Ltd. 2000). Rance *et al* (1995, 1998) were of the opinion that ASSRs addressed the major shortcomings of ABR testing in that ASSR was an alternative frequency-specific approach, which does not suffer the spectral distortion problems associated with short duration stimuli. ASSRs are periodic scalp potentials that arise in response to regularly varying stimuli such as a sinusoidal amplitude- and or frequency modulated tone (Rance *et al* 1998).

From the definition, it can be seen that ASSRs are evoked by the use of novel stimuli in that the technique uses rapidly changing auditory stimuli and the stimuli are presented at such a high rate as to cause overlapping of the responses to the stimuli. The response obtained is thus not a transient response elicited by a rapid change in an auditory stimulus. A steady state response is elicited by a sustained sound or the continuation of a stimulus (Stapells, Linden, Suffield, Hamel and Picton, 1984).

ASSR also depends on different techniques to evaluate their presence. Transient responses like ABRs are usually described in terms of the amplitudes of specific waves and the latencies of these waves, whereas ASSRs are not measured in the time domain but in the frequency domain. Lins *et al* (1996) explained that the compound electrical activity recorded contains the spectral component at the rate of modulation of the tone presented.

Of the various applications of this new AEP, ASSR, that have been proposed in the literature, audiogram estimation is the most important clinical application, especially in difficult- to -test populations.

The pseudohypacusic patient falls into this difficult-to-test category and, with the available knowledge of ASSRs the following questions have been posed:

- ? Would ASSR testing be an accurate, feasible and time efficient way in which pseudohypacusic mineworkers with noise-induced hearing loss could be evaluated?
- ? Will the threshold estimation in the group who are difficult- to- test but also do have true sensory-neural hearing loss be accurate enough to obviate further diagnostic procedures?
- ? Will it give the required information to finalise compensation and fitness calculations?

Based on the limitations of current audiological procedures in evaluating pseudohypacusic NIHL cases, the present study was undertaken to determine the clinical value of auditory steady state response (ASSR) tests in this application. Implementation of ASSR testing for audiological assessments of NIHL cases offers the potential benefits of accurate threshold determinations with significant cost savings for employers and their insurers, through the elimination of overcompensation and unnecessary referrals and retests. Savings are also envisaged through the elimination of unproductive shifts. Secondary benefits include greater efficiency at audiological test centres, through the application of current knowledge and state-of-the-art methods to ensure internationally accepted best practice in the evaluation of noise-induced hearing loss.

1.3 Aims of the research

The aim of the study was to assess the clinical value of ASSR methods for the diagnosis and assessment of pseudohypacusis in mineworkers being tested for NIHL.

In order to decide on the clinical value of ASSR methods it was necessary to:

- ? assess the sensitivity of ASSR techniques in the estimation of hearing thresholds for noise-exposed mineworkers, with noise-induced hearing loss.: thresholds should be sufficiently accurate for compensation purposes, as well as for assessments of fitness-for-work;
- ? determine the comparative effectiveness of available stimulation methods in ASSR testing. Multi-frequency (MF) and single frequency (SF)-ASSR methods are available for threshold estimates: the single frequency method entails testing one frequency in one ear much the same as with pure tone audiometry. The MF method tests four frequencies simultaneously in both ears;
- ? identify the best modulation frequency for the testing of adults with impaired hearing: modulation frequencies of 40 per second and 80 to 110 per second are possible;
- ? compare the time-efficiency of MF- and SF-ASSR methods,
- ? assess the practicability and costs of ASSR testing in mines' audiological procedures.

2 Methods

2.1 Research design

To determine the clinical value of ASSR techniques, an experimental research method was selected for this study (Leedy 1997). The research was also quantitative in nature. Berg (1998) defines quantitative research as *“providing rigorous, reliable, and verifiably large aggregates of data and the statistical testing of empirical hypotheses”*

Results from conventional threshold testing were compared to threshold estimation procedures using ASSR tests. The comparison of the gold standard with ASSR tests made it possible to evaluate the validity, accuracy and sensitivity of ASSR tests.

To exclude any possible effects of other variables mentioned in the literature the following variables were controlled:

- ? Gender: all subjects were male.
- ? Age: all subjects were between 23 and 60 years of age.
- ? Middle ear function: all subjects had normal tympanograms and a normal otoscopy results.
- ? Exclusion of other causes of SNHL. All subjects were diagnosed with noise-induced hearing loss and had documented noise exposure of more than five years (Odendaal 2003, Begley 2003).

After the most suitable ASSR procedure was determined, a sample of pseudohypacusic workers was also evaluated with the determined protocol.

At the time of the experimental research there were two ASSR systems available in South Africa, the Audera Beta- and Biologic system. Both these systems were evaluated.

The Audera could also test at different modulation frequencies and thus both 40- and 80 Hz modulation was experimented with.

During experimental testing and especially with evaluating the 80 Hz modulation that was commenced with the researcher experienced difficulty in obtaining thresholds due to background EEG activity. After HASS (the importer of the Audera equipment) inspected the premises and experimental set up it was recommended that the subjects be sedated as is recommended in literature. This procedure is routinely followed in the clinical testing

of pseudohypacusis mineworkers (Bezuidenhout 2003) when ABR testing is done. The sedation was done under the supervision of OMPs and an Ear, nose and throat specialist.

An explanation of the research design is given in Table 2.1.

Table 2.1
Research design of present study

Instrument	MF (Hz)	Sedation	No. subjects	Diagnosis
Audera Beta	80	No	12	NIHL
Audera Beta	40	No	16	NIHL
MASTER Biologic	80-110	No	20	NIHL
Audera	40	yes	13	NIHL
MASTER Biologic	80-110	yes	13	NIHL
Audera	40	Yes	29	Pseudohypacusis

2.2 Subjects

Non-probability quota sampling (Neuman 1997) was used in this study, i.e. the selection of anyone in the predetermined group. All potential subjects complying with the selection criteria were selected, within the time constraints imposed by length of working day and the lengthy test procedures. A three-month period was allowed for experimental research, i.e. September to November 2002.

2.2.1 Population.

A population of mineworkers (gold) was selected from workers undergoing annual Certificate of Fitness assessments at their mines' Occupational Health Centres in the Randfontein and Carletonville areas. All subjects worked underground and, hence, were exposed to hazardous noise. Experimental testing was conducted on the same day, to prevent interference with normal production at the mines. Same day inclusion was not always possible in cases where workers were sedated since workers had to consult an ENT specialist or OMP to peruse their medical history in order to prescribe sedation.

2.2.2 Sample Selection

A total of 110 male (220 ears) mineworkers working underground between the ages of 23 and 60 were selected consecutively from workers presenting for annual medical surveillance with proven noise-induced or SNHL (pure-tone average in excess of a 25 dB for 500; 1000; 2000; and 3000 Hz) i.e. abnormal and potential compensable hearing. Of the 110, 81 subjects formed the normative group and 29 were later classified as pseudohypacusic. The normative group used to establish if ASSR threshold estimates correlated sufficiently with pure-tone thresholds was divided into five sub-groups to study different test protocols. Protocols were selected on the basis of previous findings that:

- ? responses for 40 Hz (Rance *et al.* 1995) and 80-110 Hz (Rickards and Clark 1998) are useful in estimating hearing thresholds.
- ? SF- and MF-ASSR techniques can provide reliable threshold estimates (Perez-Abalo *et al.* 2001; Rance *et al.* 1995). Both these monotic and dichotic stimulation techniques have not been previously validated for noise-exposed populations.
- ? The literature advocates the use of sedation to minimise artefacts and background noise (Hood 1998). It is the researcher's experience that pseudohypacusic mineworkers tend to be nervous during ABR testing, since they are unable to influence threshold recordings and are aware that their exaggerated hearing loss is likely to be revealed.

The results of the 81 normative subjects were used to determine the most effective test equipment, stimulation rate and stimulation method (MF or SF), as well as the effect of sedation. It was thus possible to decide on a protocol of choice for a population with NIHL. The selected protocol was finally applied to 29 workers with pseudohypacusis to satisfy the principal aim of the study, i.e. to evaluate ASSR testing for pseudohypacusic mineworkers. The pseudohypacusic subjects were sedated and tested with a SF 40 Hz technique, to evaluate ASSR method's effectiveness in concluding pseudohypacusic workers' assessment procedures.

2.2.3 Employer permission and ethics approval.

Informed consent was obtained in writing from each subject, with the assistance of an African languages translator. Workers refusing to participate were routed back for continuation of standard medical surveillance procedures (one subject). Permission to involve their employees was obtained from mining companies whose workers participated and ethics clearance was obtained from the University of Pretoria Research Ethics Committee.

2.3 Testing procedures and equipment

2.3.1 Pure-tone audiometry

The results of pure-tone air-conduction screening audiometry performed at mines' Occupational Health Centres were used to select subjects with abnormal hearing (potential compensable NIHL cases). Subjects had to present with pure-tone averages loss in excess of 25 dB (for 0,5; 1; 2; and 3kHz) in both ears. These frequencies were selected because they are used for evaluations of fitness and compensability (WCC Instructions 168 and 171), and they were also used as a basis for comparison with ASSR thresholds.

Pure tone air and bone conduction audiograms performed by audiologists on the same subjects served as a control over the first screening thresholds and further limited the process to only including subjects with sensory-neural hearing loss. The testing was performed in calibrated sound booths.

The audiometry was performed by audiologists using a calibrated Madsen OB 822 and GSI 60 diagnostic audiometer.

Pure-tone audiometry was performed using descending steps of 10 dB and ascending steps of 5dB, with a 50 per cent positive response at the same level taken as the threshold. Thresholds were determined first for the left ear and then for the right.

2.3.2 Case history

A case history (Appendix A) was recorded by a trained African languages translator, to confirm exposure to hazardous noise and exclude other possible causes of SNHL, e.g. ototoxic drugs, ear infection or head injury. Case histories also ensured that subjects were selected in accordance with adopted criteria for age and gender.

2.3.3 Otosopic examination

Otosopic examinations were performed by audiologists 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 (Stach 1998). A Heine mini 2000 otoscope was used.

2.3.4 Tympanometry

Functioning of the middle ear was assessed by means of immittance testing (tympanometry) to exclude any subjects with middle ear involvement, since this can influence ASSR results (Hall and Chandler 1994). Furthermore, the focus of the present study was sensory-neural hearing loss and specifically NIHL, and not conductive or other types of hearing loss. A GSI 33 middle ear analyzer and a Beltone 2000 immittance tester, both of which were calibrated prior to testing, were used. Selection criteria (to ensure normal middle ear function) applied to tympanometry results were:

- ? Ear canal volume: 0,5-1,5 cc
- ? Compliance: 0,3-1,6 cc (Stach 1998)

2.3.5 Pseudohypacusis

After a normative group of workers with proven SNHL has been tested, a group of subjects displaying pseudohypacusis was tested using ASSR methods. Two pure-tone audiograms were performed at 0,5; 1; 2; 3 and 4 kHz, to enable threshold comparisons for the purpose of identifying pseudohypacusis. A difference of 15 dB or more (Rintelmann *et al*/1991) at any frequency and in both ears was regarded as an indication of pseudohypacusis. The two audiograms recorded used different threshold determining techniques, viz. the ascending and descending methods (Rintelmann *et al* 1991).

2.4 Data collection equipment and procedures.

Four sets of data were collected from each subject in the normative NIHL group, namely two pure-tone air-conduction tests, (0,5; 1; 2; 3 and 4 kHz), ASSR thresholds and the test duration for each ASSR procedure. Data from each subject were collected on the same day, starting with pure-tone testing (which also served as a subject selection procedure). Audiologists performed data collection procedures either at the Occupational Health Centre in Randfontein or in Carletonville.

For the pseudohypacusic group of 29 subjects, the following sets of data were obtained. These included two pure-tone air-conduction threshold tests at 500; 1000; 2000; 3000 and 4000 Hz (ascending technique, followed by the descending method), SF-ASSR results under sedation using a 40 Hz modulation rate and, lastly, the time required for testing.

As many as possible of subjects' previous screening results were obtained from records at the OHC to confirm inconsistent responses.

2.4.1 Pure tone testing.

Pure-tone thresholds were obtained using the same calibrated audiometers and acoustic enclosures as detailed in the preceding section (2.3). The pure tone tests thus served as both a criteria for subject selection and as experimental data.

2.4.2 MF-ASSR testing.

MF-ASSR responses were recorded with a Master Auditory Steady-State Response system (MASTER), a Windows-based test and data acquisition system developed by Bio-logic Systems Corporation (2002). The MASTER system includes both software and hardware and requires a personal computer. Bio-Logic's Navigator Pro TM unit performed the necessary analogue-to-digital and digital-to-analogue conversions, including production of the stimulus output to earphone inserts and gathering of EEG input from electrodes. The navigator Pro was connected to the computer's serial port for use of the RS-232 communication protocol. Computer hardware specifications were:

Computer system.

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

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.

- ? Navigator Pro TM EP unit and accessories.

Disposable ear probe tips were supplied by Bio-logic Systems Corp. Electrodes were latex-free and made of hypoallergenic material. ASSR measurements were obtained in a calibrated environment.

Two groups of subjects were tested using a dichotic MF-ASSR technique, one without sedation and the other with sedation, to obtain thresholds at 500; 1000; 2000; 3000 and 4000 Hz. Multiple AM tones were selected with the same carrier frequencies (CF), modulated between 70 and 110 Hz. CFs were spaced at least one octave apart (Perez-Abalo *et al*/2001), and four frequencies were simultaneously evaluated (dichotic) for each ear. Previous studies have indicated that a modulation rate of 80-110Hz is appropriate for adults and that there are no significant differences between results from SF- and MF techniques (Lins and Picton 1996). Time efficiency could also be evaluated in this way, since the design of the experiment left options for comparing the time required for SF- and MF techniques.

In the sedated group, 10 mg of Valium was given per mouth after informed consent and medical clearance¹. A medical doctor (OMP) was present for medical backup, and testing commenced one hour later, to allow time for the medication to be absorbed.

An electrode skin-preparation swab coated with Nuprep was used to clean areas where electrodes were to be affixed. The skin was further cleaned with an ear bud and abrasive paste (Nuprep). 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-ohms between electrodes (Biologic2002).

Earphones probes were then inserted, using a disposable ear tip appropriate for 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 juxtaposition of results for right and left ears.

Electrodes were placed on the:

- ? Mastoid process (L).
- ? Mastoid process (R).
- ? High forehead as recommended by Biologic (2002)

¹ The routine ABR testing procedure was followed to administer valium and follow up the subject.

Test parameters used during this MF-ASSR procedure were the default values as determined by the software supplied by Biologic (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 impacting on data collection at frequencies between 80-100 Hz (Biologic2002). Testing was performed in a sound proof booth and the air conditioning in adjacent rooms was switched off, as were 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.

Power to the system was not switched on or off while a subject was connected to the system, to ensure safety. Threshold determination occurred within a HL range of -20 to 120 dB, and the software warned the researcher when very high intensities were selected.

The software recorded test data, and provided an exact measurement of the time taken for each subject. Electrophysiological thresholds were eventually determined from responses obtained, based on a requirement for a less than 5per cent chance of the subject's response being attributable to chance (f-ratio statistics at a 0,05 level of confidence). The electrophysiological thresholds were finally converted to behavioural thresholds by subtracting 10 dB to predict a conventional audiogram (Biologic 2002).

Carrier frequencies

Default protocols were selected in order to obtain thresholds (four per ear) at 500; 1000; 2000; 3000 and 4000 Hz. Default protocols prevented testing at all frequencies required by WCC 168/171 in a single stimulation sequence, thereby requiring more than one set of stimulus presentations.

Modulation frequencies

Table 2.4.2

Modulation frequencies used by MASTER

CF	500 Hz	1 000 Hz	2 000 Hz	3 000 Hz	4 000 Hz
MF	86,914 Hz	89,844 Hz	91,797 Hz	83,008 Hz	94,727 Hz

AM percentage

The attenuation of the carrier was kept at the default value of 10 per cent

Number of sweeps

The software determined the number of sweeps (average) the MASTER ran per subject and per test, using 32 sweeps per threshold in accordance with the current protocol (Biologic 2002).

Epochs per sweep

The number of epochs collected per sweep before the 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 recorded sweeps, divided by the number of sweeps collected.

2.4.3 SF-ASSR testing

SF-ASSR data were collected with 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, 1,4 MB 3,5" diskette drive and pointing device (mouse/touch pad), running Windows XP.
- ? UCB connector.
- ? Audera software.
- ? Audera unit.
- ? Audera amplifier.
- ? Electrodes.
- ? GSI tip-50 insert 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) loaned the commercial 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.

SF-data collection procedures with the GSI Audera (Grason-Stadler) were applied to a group of sedated mineworkers with noise-induced hearing loss, as well as to two groups of subjects with NIHL who were not sedated. This allowed comparisons to be made for

determining the most advantageous “state of consciousness” during ASSR testing. The two non-sedated groups were compared through use of different stimulation rates (40Hz and 80Hz). Both of these rates had been found to provide reliable estimates of behavioural thresholds during previous research.

Thresholds were required for 500, 1000; 2000; 3000 and 4000 Hz, to allow comparisons of SF-ASSR, MF-ASSR and pure-tone thresholds. ASSR thresholds were obtained using both ascending and descending threshold-seeking procedures, starting at a HL of 40 dB, as with behavioural testing, and increments of 10 dB were used to make thresholds more comparable with those from MF-ASSR tests and to limit testing time. SF-ASSR tests were performed immediately after pure-tone testing, to ensure that all procedures were completed on the same day. For sedated subjects, one hour was allowed for absorption of the 10 mg of Valium, with the same provisions made for consent and medical support as those for MF-testing.

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

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

Figure 2.4.3a illustrates electrode placement for the Audera system.

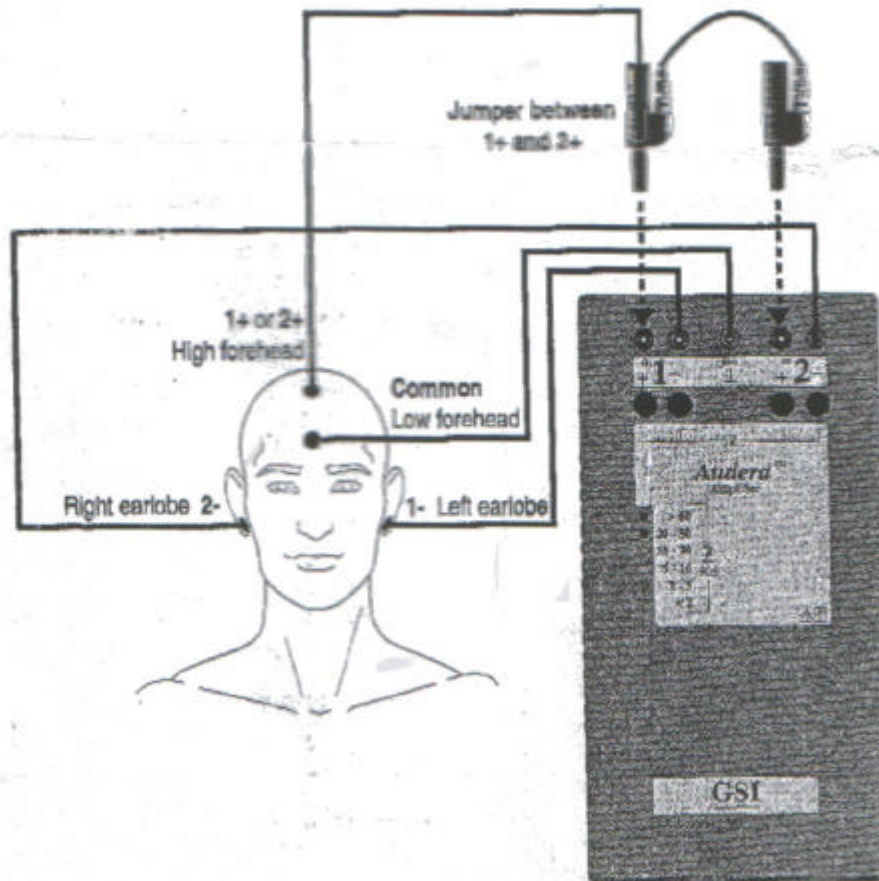


Figure 2.4.3a *Electrode placement with Audera* (HASS Southern Africa).

The same skin preparation procedures were used as for MF-ASSR tests before affixing reusable 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, electrodes were removed and thoroughly cleaned in soap and water with a soft brush.

Both the instructions to subjects and the test environment were similar to those for MF-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 MF-tests.

Testing and data collection parameters were as follows:

1. Carrier frequencies.

CFs of 500, 1 000, 2 000, 3 000 and 4 000Hz were used to allow comparisons between SF, MF and behavioural thresholds. Only with the Audera system was it possible to test at 3000 Hz with the commercial version, as the Beta version's test software made no provision for this particular frequency.

2. Modulation frequencies.

Two modulated frequencies were compared, viz. 40 Hz (awake) and 80 Hz (asleep).

3. FM and AM modulation.

Modulation rates used were the default values of 10 per cent for FM, and 100 per cent for AM.

4. Number of samples.

Sixty four samples were taken per CF and hearing level set, e.g. 1 000 Hz at 30 dB.

5. Statistical measures.

For each EEG sample, the magnitude and phase of EEG activity corresponding with the frequency of tone modulation were quantified. Magnitude and phase information was shown as a vector in a polar plot, with vector length corresponding with magnitude and vector angle reflecting the phase or time delay between tone modulation and the brain's response. Figure 2.4.3b illustrates a polar plot for a case where both the ear and the brain respond to a tone. The plot vectors are clustered, indicating a "phase-locked" brain response.

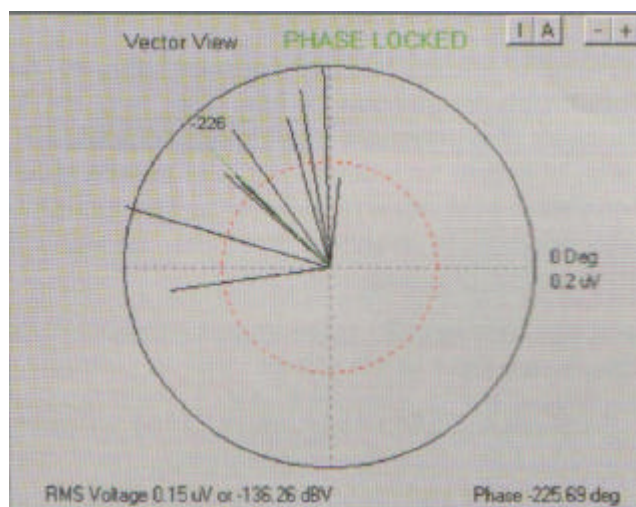


Figure 2.4.3b *Phase locked response.*

Figure 2.4.3c shows 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 EEG and the tone modulation, i.e. no response.

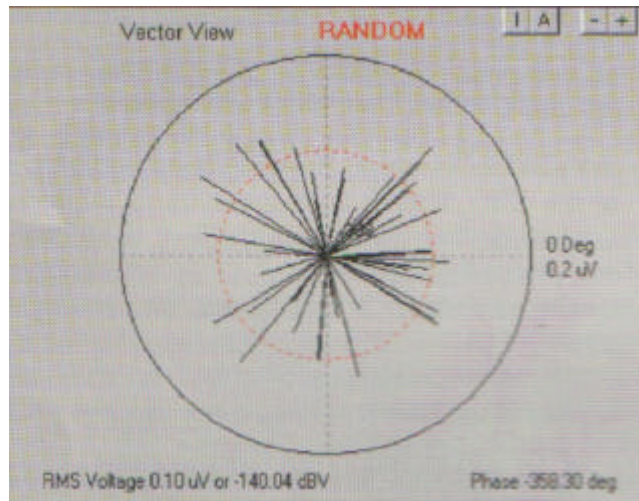


Figure 2.4.3c *Random response.*

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 SF-technique at three per cent, and any trial contaminated with excessive noise was automatically terminated and labelled accordingly, as shown in Figure 2.4.3d.

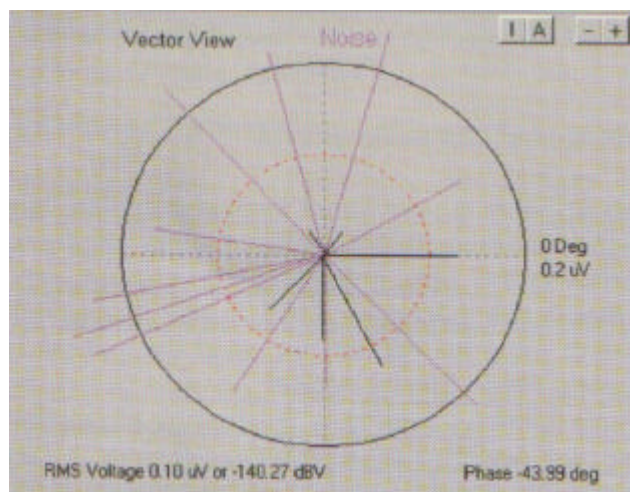


Figure 2.4.3d *Example of result rejected due to excess noise*

The results of all trials were plotted on a graph (Figure 2.4.3e), with phase-locked results marked by an upward-pointing arrow to indicate that the ASSR threshold was better than its corresponding behavioural threshold. Conversely, “random” or no-response results were marked with a downward-pointing 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. Behavioural thresholds were estimated based on an algorithm developed by Rance *et al* (1995).

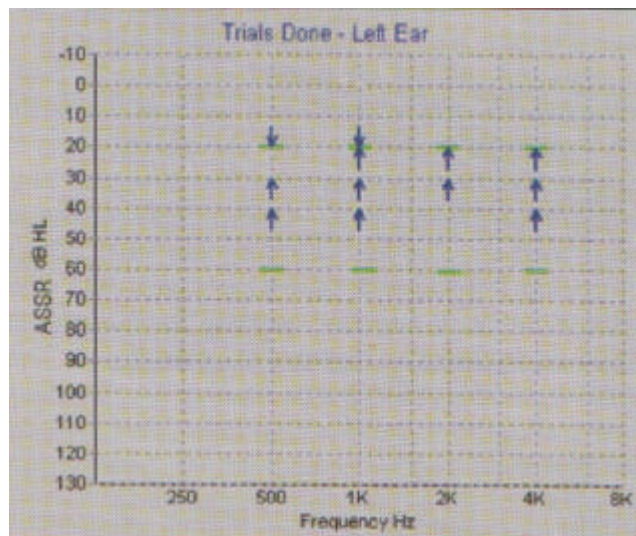


Figure 2.4.3.e *Plotted results of trials during an ASSR test.*

Estimated pure-tone audiograms such as that shown in figure 2.3.4f were compared with MF-ASSR and conventional behavioural thresholds.

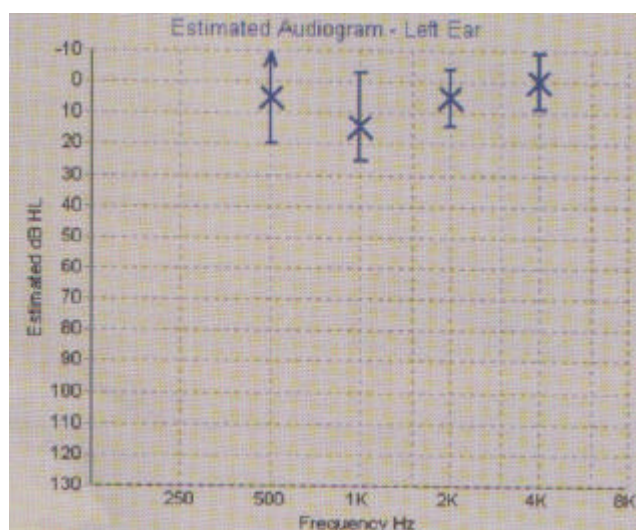


Figure 2.4.3 f *Estimated pure-tone audiogram based on ASSR results.*

2.5 Data analysis equipment and procedures

Data analysis was performed using Microsoft Excel for Windows (1998)(Levin 2003).A Microsoft Excel (2000) spreadsheet was used to collate data, which were analysed by the Medical Research Council (Levin 2003). 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 (Newman 1997).

ASSR and conventional pure-tone diagnostic methods were compared using a two-sample ttest and two-way analysis of variance (Levin 2002), with a sample size large enough to ensure that the limits of agreement could be reliably calculated. Given that only three subjects could be tested during each working day, one full month of testing was allowed for evaluating approximately 60 subjects, which was deemed sufficient to reliably calculate limits of agreement (Levin 2002). The study's classification as an exploratory study indicated that a sample size of 60 was adequate to compare ASSR methods with conventional pure-tone testing (Levin 2002), but a total of 81 subjects were ultimately tested.

3 Results and discussion.

3.1 Age distribution of subjects-normative group.

The normative group consisted of 81 male mineworkers with NIHL, between the ages of 23 and 60 years. Figures 3.1a - e represent the age distributions of mineworkers with NIHL across five-year age intervals.

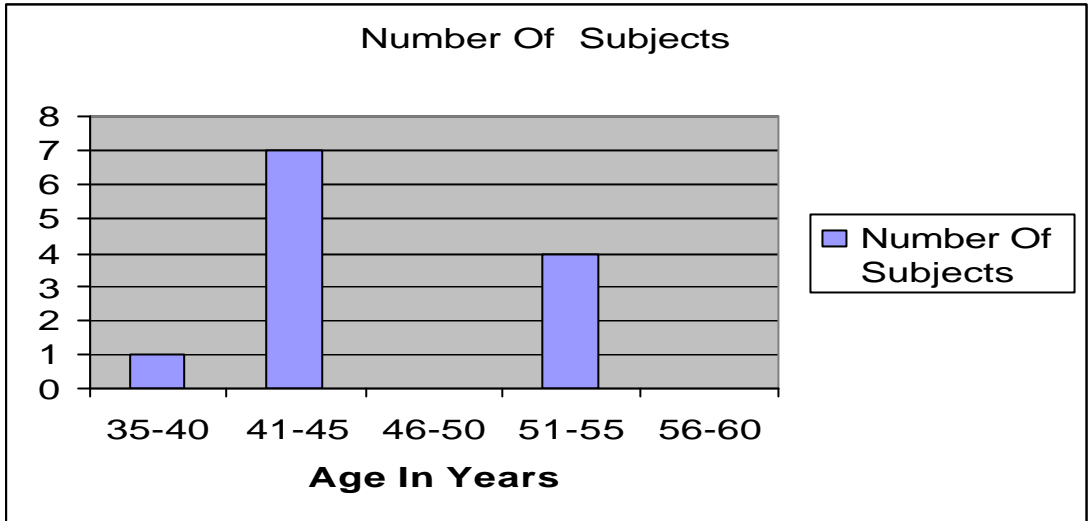


Figure 3.1a Age distribution of the SF/80Hz/ non-sedated group (n=12):
Mean age 45,8 years.

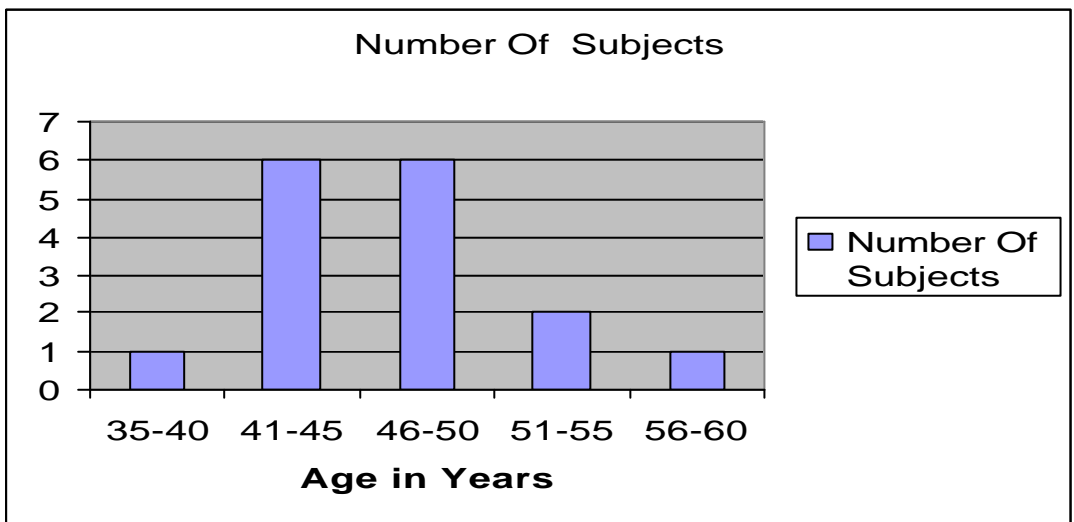


Figure 3.1b Age distribution of the SF/40Hz/ non-sedated group (n=16)
Mean age 47,5 years.

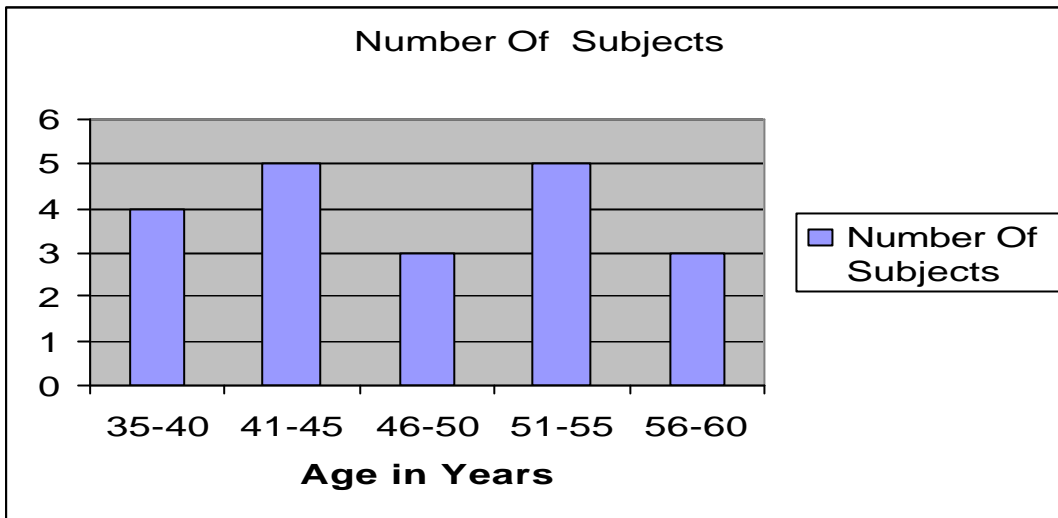


Figure 3.1c Age distribution of the MF/80Hz/non-sedated group:
Mean age 46,38 years.

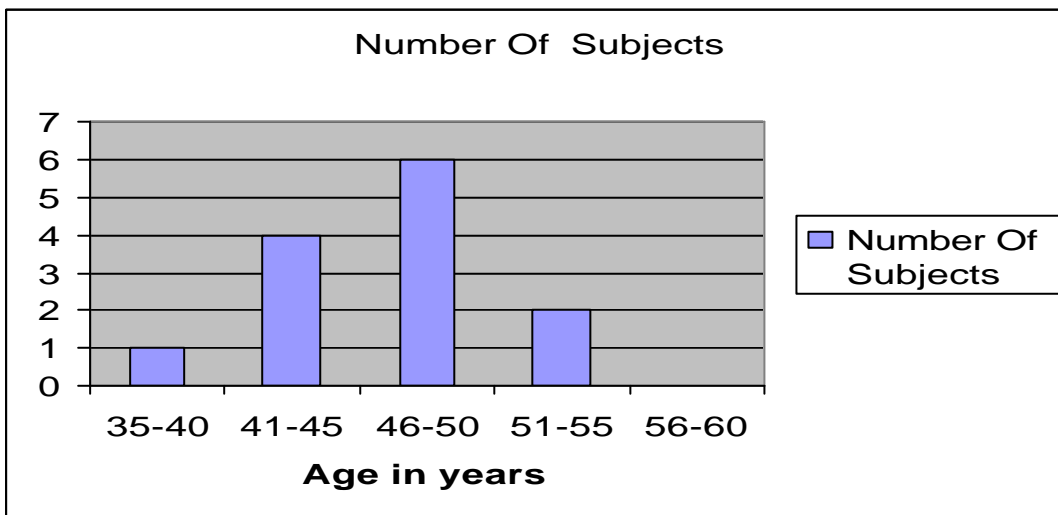


Figure 3.1d Age distribution of the SF/40Hz/ sedated group (n=13):
Mean age 47,3 years.

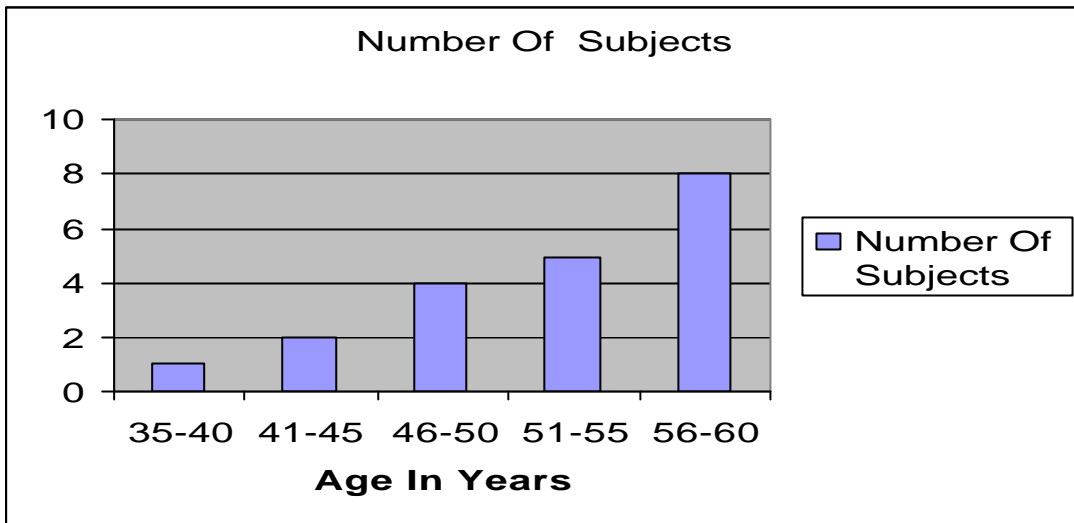


Figure 3.1e Age distribution of the MF/80Hz/sedated group (n=20):
Mean age 52 years.

3.2 Exposure of subjects-normative group.

Figures 3.2 a - e illustrate the experience or years of noise exposure of the subjects.

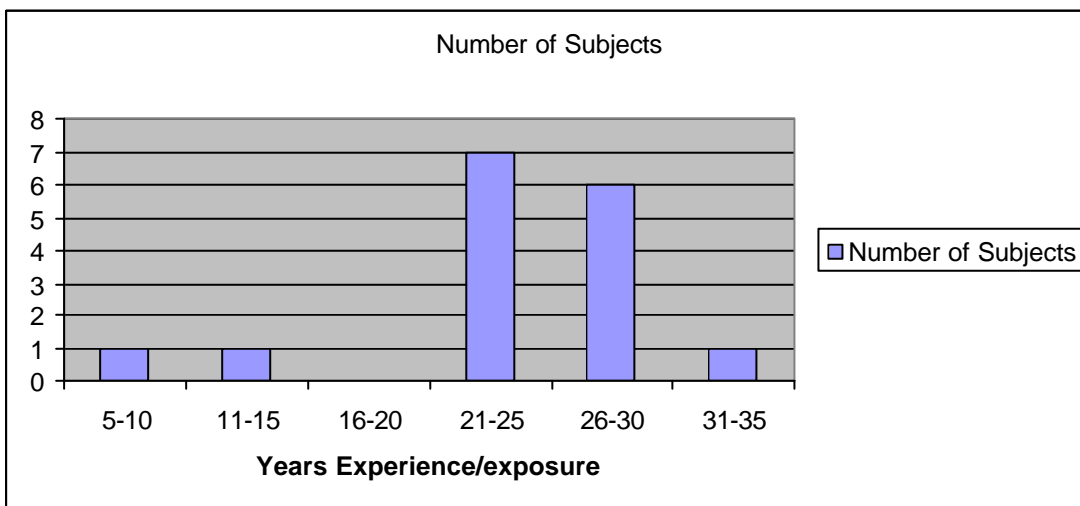


Figure 3.2a Experience/exposure: SF/80 Hz/non-sedated group.

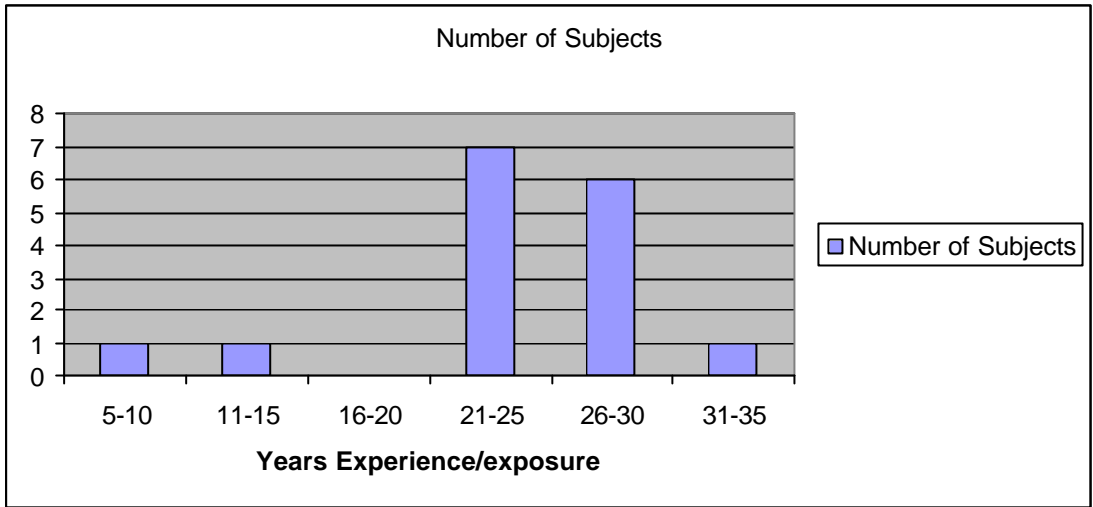


Figure 3.2b Experience/exposure: SF/ 40 Hz/ non-sedated group.

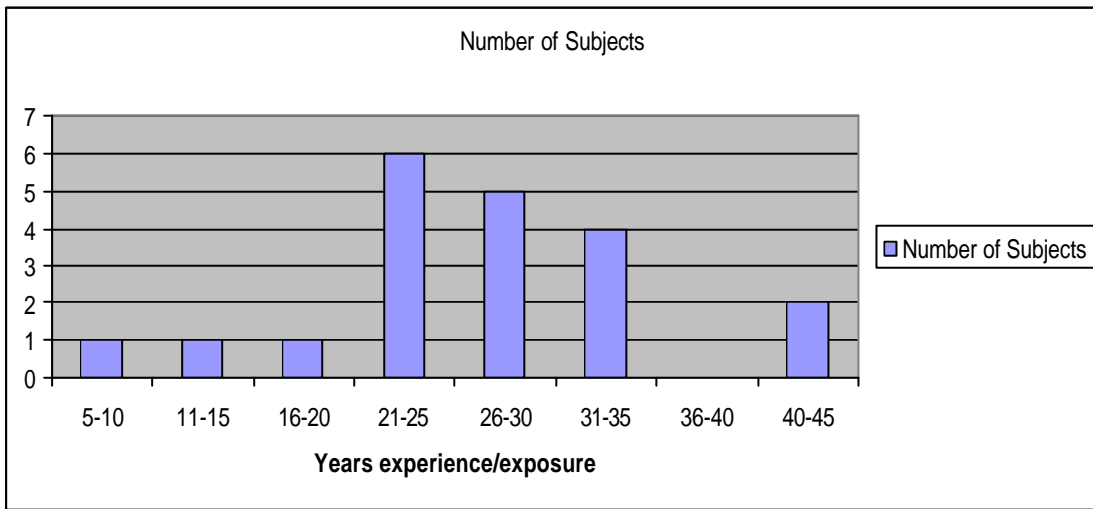


Figure 3.2c Experience /exposure: Biologic/MF/non-sedated group.

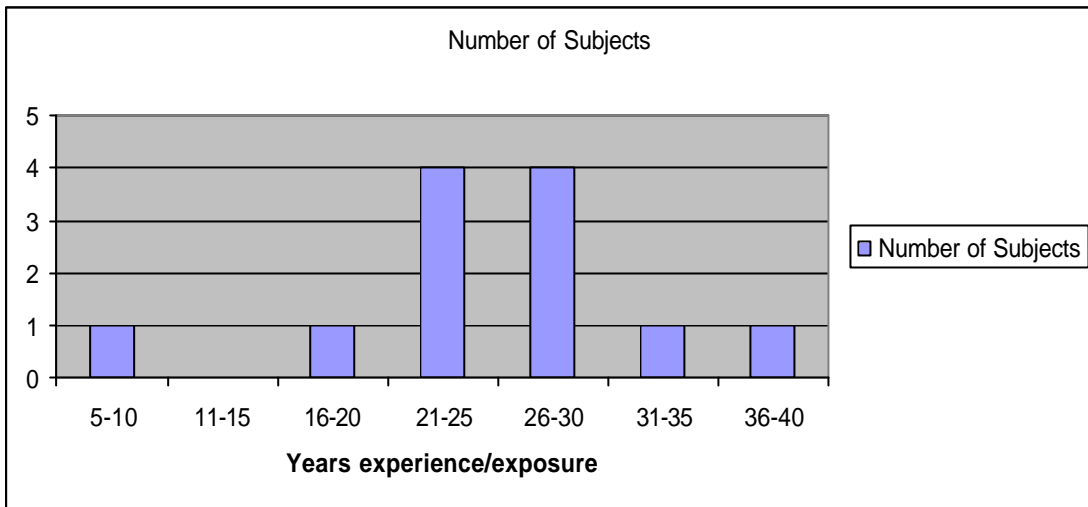


Figure 3.2d Experience/exposure: SF/40 Hz/sedated group.

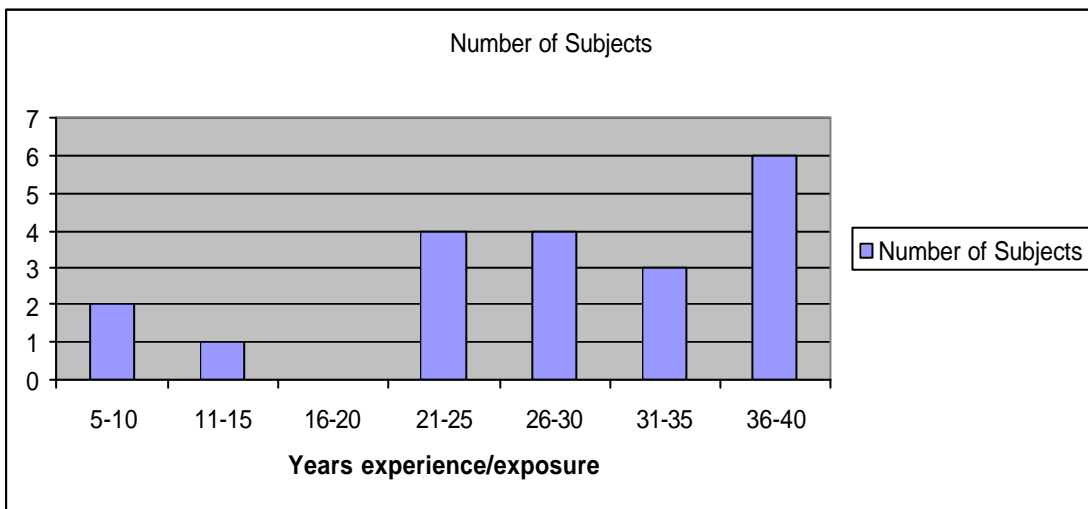


Figure 3.2e Experience/exposure: MF/sedated group.

3.3 Age distribution of pseudohypacusic group.

The group of mineworkers with pseudohypacusis consisted of 29 subjects. Their age distribution and noise exposure are shown in Figures 3.3 a and b respectively.

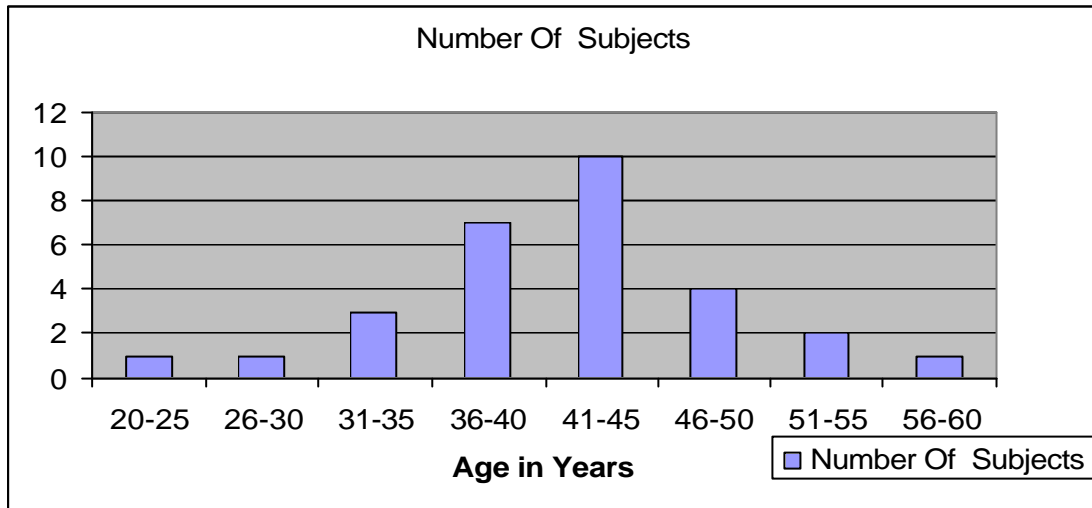


Figure 3.3 Age distribution of pseudohypacusic group:
Mean age 41,86.

3.4 Noise exposure of pseudohypacusic group.

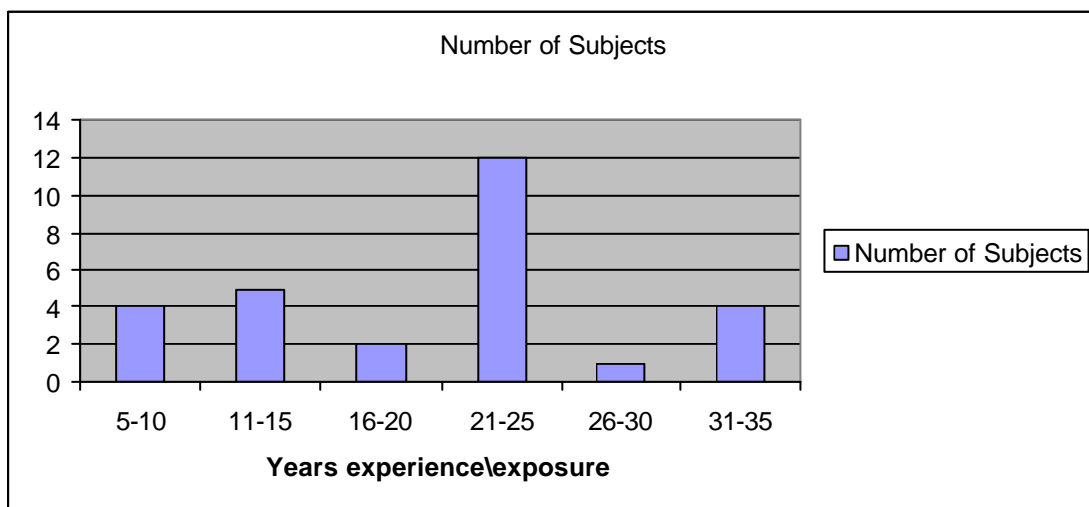


Figure 3.4.: Experience/exposure. Pseudohypacusic group.

3.5 Clinical value of ASSR tests.

Schmulian (2002) quotes Roeser, Valente and Hasford-Dunn (2000), who stated that the value of any diagnostic test depends on its ability to fulfil the intended purpose. The principal aim of the present study was to assess the clinical value of ASSR methods in the audiological evaluation of pseudohypacusic mineworkers, particularly those with noise-induced hearing loss (NIHL), and the accurate determination of hearing thresholds for assessing compensability and fitness for work.

The present study differs from previous work, in that it considered subjects with abnormal hearing, specifically those with NIHL, a specific form of sensory neural hearing loss (SNHL). Various protocols and instruments were compared, to identify the most appropriate and practicable procedure for assessing pseudohypacusic mineworkers with NIHL. Because such individuals are often inclined to withhold cooperation during test procedures, the use of sedation 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 for industry.

Because NIHL is sensory neural in nature, subjects' hearing was most affected at the higher frequencies and, thus some subjects had normal hearing at the lower frequencies. Figure 3.5a indicates the number of normal thresholds included in the sample of 648 pure-tone thresholds recorded.

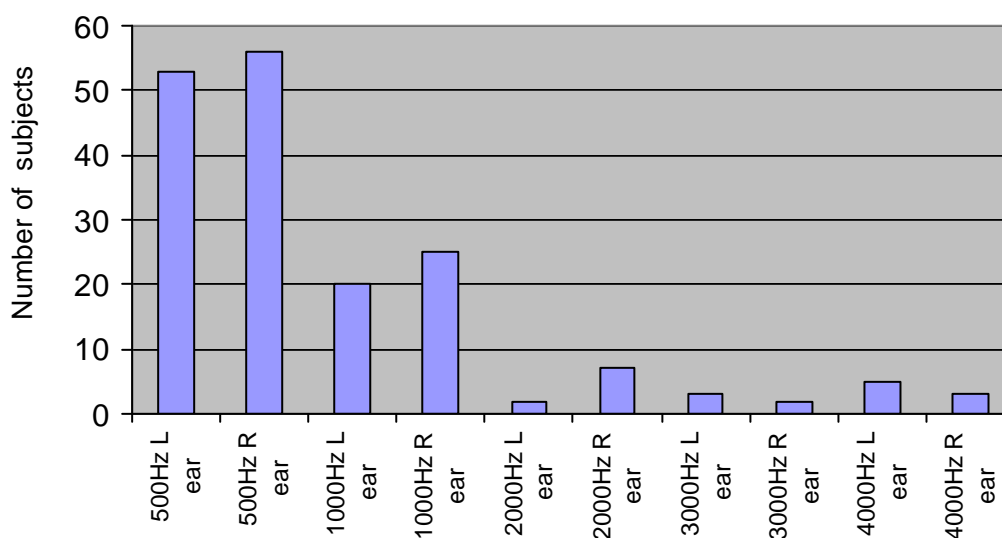


Figure 3.5a Number of subjects with normal pure tone thresholds ($\leq 25\text{dB}$) for given ear and test frequency.

It can be seen from the figure that the usefulness of ASSR techniques was also unintentionally evaluated using 176 normal thresholds, of which the majority were in the 500-1000 Hz range.

Six hundred and forty eight (648) pure-tone thresholds were compared with 536 ASSR thresholds, the discrepancy being due to the Audera Beta (prototype) instrument's lack of provision for testing at 3000 Hz (12 subjects x 2 thresholds = 24), and the Biologic instrument's capacity to determine only eight thresholds at once, making it necessary to test 3 000 Hz separately, thereby extending what was already a lengthy procedure. Table 3.5a gives the mean thresholds obtained for all frequencies tested in the normative group of 81 subjects (ASSR and pure-tone), while Table 3.5b compares thresholds from ASSR and pure-tone testing for left and right ears and Table 3.5c gives the differences between mean thresholds from ASSR and pure-tone testing.

Table 3.5a

Sensitivity of ASSR and pure-tone testing by test frequency

Test frequency (Hz)	Threshold estimation technique	Mean Threshold/SD (dB)	t and p values from paired t-test
Left ear			
500 Hz	ASSR	28,8/15,5	t=2,61
	PT	20,6/10,8	p=0,011
1 000 Hz	ASSR	39,8/12,5	t=3,1
	PT	36,3/12,8	p=0,003
2 000 Hz	ASSR	48,1/11,2	t=1,97
	PT	45,5/10,3	p=0,05
3 000 Hz	ASSR	54,5/14,6	t=2,14
	PT	49,8/13,2	p=0,05
4 000 Hz	ASSR	52,96/15,59	t=2,95
	PT	49,91/13,86	p=0,0047
Right ear			
500 Hz	ASSR	27,81/16,0	t=4,4553
	PT	19,60/10,44	p=0,000
1 000 Hz	ASSR	40/12,19	t=3,57
	PT	36,03/13,37	p=0,0007
2 000 Hz	ASSR	47,27/12,45	t=3,23
	PT	43,52/10,38	p=0,002
3 000 Hz	ASSR	48/12,40	t=-0,514
	PT	49,25/11,15	p=0,6129
4 000 Hz	ASSR	50,72/14,95	t=1,62
	PT	49 (13,38	p=0,1103

Table 3.5b

Comparison of pure-tone and ASSR results for left and right ears

Five-frequency mean for given ear	Threshold estimation technique		Mean threshold (dB)	SD
Left ear	ASSR	(n=68)	41,7	9,3
	PT		40,03	7,78
Right ear	ASSR	(n=73)	42,1	9,6
	PT		39,6	8,1
Overall mean for both ears	ASSR	(n=78)	42,4	8,9
	PT		39,97	7,4

Table 3.5c

Mean difference between ASSR estimated and pure-tone thresholds

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

From the preceding three tables it is apparent that ASSR thresholds (the experimental method) and pure-tone thresholds (the “gold standard”) correlated well enough to make ASSR testing a clinically acceptable measure. The mean difference in thresholds from the two methods was never more than 10 dB (the acceptable inter-test difference for reliability) (WCC 1995 and 2000). The largest difference of 8.2 and 8.21 dB (L and R) occurred at 500 Hz (Table 3.5a), which is in accordance with previous findings (John *et al.* 2000, Lins *et al.* 1996, Schmulian 2002, Herdman, Stapells 2001). Rance *et al.* (1993) also describe larger response amplitudes for higher test frequencies. This reduced ability to accurately estimate lower frequency thresholds has been explained as a result of intrinsic jitter, where the activation pattern along the basilar membrane covers a larger

area for lower frequency stimuli. Lins *et al.* (1996) also refer to the masking effect of background noise on 500 Hz steady-state stimuli. This is not applicable in the present study, since testing was done in an acoustically treated booth, as was also the case with pure-tone testing.

The same authors also postulated that stimuli at 500 Hz may be masked by higher frequency signals during MF-ASSR testing. This could have affected the present study, since SNHL made it necessary to use high-intensity stimuli at the higher test frequencies. Another explanation may be that ASSR-based thresholds for lower test frequencies, particularly 500 Hz, were the closest to normal hearing (average pure tone thresholds were 20.6 and 19,6 dB respectively and there were 172 normal thresholds). ASSRs have been found to favour abnormal hearing (John and Picton 2000, Schmulian 2002), as a result of recruitment.

To reduce test time, the present study used 10 dB intervals during threshold-seeking procedures for both MF- and SF-ASSR tests, in accordance with accepted practice for AEP methods. 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 obtained were less than for many previous studies (30-34 dB: Swanepoel 2001, 8-18 dB: Lins and Picton 1995, 28-34 dB: Aoyagi *et al.* 1994). One explanation for the smaller mean differences from the present study is that ASSR instrumentation and algorithms have improved in recent years, and the latter have benefited from use of weighted averaging techniques (John *et al.* 2001). The same authors also note better response detection with the introduction of mixed modulation methods, which were used during the present study.

Present results indicate that ASSR thresholds were accurate throughout the severity range, with 176 normal thresholds, as well as severe to profound thresholds. The normative group with sensory-neural hearing loss can be described as middle-aged (mean age 47.80 years), but age should not have affected the accuracy of ASSR thresholds, based on previous findings that age has little or no influence on this parameter (Siniger and Cone-Wesson 1994).

There is considerable clinical value to be derived from the fact that there was no influence from the researcher in determining thresholds, as an entirely objective procedure was used. The only variables that can be manipulated by the clinician during MF-testing are the number of sweeps and the extent of averaging. Swanepoel (2001) and

Schmullian (2002) both note the present lack of standards for the latter parameter, and state that more averaging is needed for stimuli with intensities near the threshold level. The Audera system, unlike the Biologic, used built-in algorithms to control the number of samples, thereby eliminating any possibility of the clinician influencing 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. 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 behavioural thresholds, this for a large population of subjects with NIHL (SNHL) across the entire severity range.

Subject-related factors such as noise from body movement were found to influence the amplitude of responses and quality of results and the test system used can also limit the practicability of ASSR testing. As previously mentioned, 536 ASSR thresholds were obtained in comparison with 648 results for pure-tone testing, due to shortcomings in both the Audera Beta (no values for 3000) and Biologic systems (8 not 10 readings). Compensation assessments require ten thresholds, but the Biologic can only determine eight thresholds in a single test run. Subject-related influences such as movement, fidgeting, coughing and sneezing (noise) also accounted for some of the shortfall in ASSR thresholds, as found in previous studies (Aoyagi *et al.* 1994) where test procedure were also lengthened by such interventions. Figure 3.5b illustrates the prevalence of factors that prevented threshold determinations.

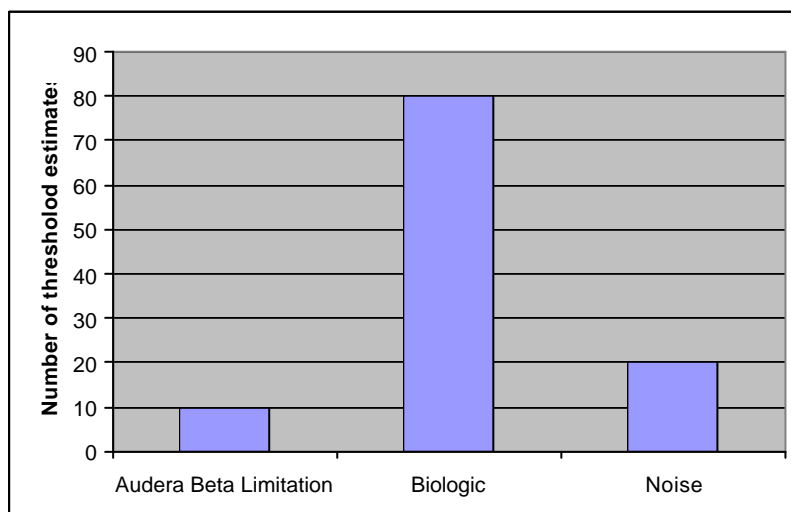


Figure 3.5b ASSR thresholds not obtained (n=112)

From the figure it can be seen that nearly 20 per cent of failures to detect threshold were due to noise. 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 deliberate disregard of instructions on the part of uncooperative subjects.

The results of this study indicate that ASSR testing is a reliable and accurate method for objectively determining frequency-specific hearing thresholds and that it can be successfully applied as an alternative to pure-tone testing for uncooperative adults with SNHL. These results have also confirmed previous findings that ASSR methods are not influenced by age of the subject (Picton 1990).

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

3.6 Effectiveness of MF- and SF-ASSR methods for estimating thresholds in a NIHL population.

Single-frequency stimulus tests were performed on 41 subjects using the Audera system. Multi-frequency stimulus testing of 40 subjects was done with the Biologic MASTER, which allowed simultaneous stimulation at four test frequencies in each ear. Table 3.6a indicates the average number of test frequencies at which a threshold was determined per subject with each technique.

Table 3.6a

Average number of frequencies completed with SF- and MF-testing

Stimulation technique	Number of frequencies	Paired t and p value
Single-frequency (Audera)	6	t=-2,39
Multi-frequency (Biologic)	7,4	P=0,0193

As can be seen from the preceding table, the Biologic yielded more thresholds, due to its ability to complete eight frequencies simultaneously, and the Audera Beta prototype's lack of provision for 3 000 Hz.

Table 3.6b indicates the average time taken for the two stimulation techniques, independent of the number of thresholds obtained, while Table 3.6c shows the time taken normalised for the number of thresholds obtained.

Table 3.6b
***Time taken for SF-and MF-tests,
independant of number of frequencies completed.***

Stimulation technique	Time (minutes)	Paired t and p value
Single-frequency (Audera)	50,44	t= -7,19
Multi-frequency (Biologic)	85,4	P=0,00

Table 3.6c
***Time taken for SF-and MF-tests,
normalized for number of frequencies completed.***

Stimulation technique	Time (minutes)	Paired t and p values
Single-frequency (Audera)	51,56	t=-6,56
Multi-frequency (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, with the SF-technique being more time-efficient. This finding contradicts previous work (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 have been of 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. Use of higher stimulation rates, as with the Biologic, is specifically intended to address the 40 Hz response's sensitivity to infants' maturation and state of consciousness, which is not a concern in the present context.

Furthermore, there are discrepancies in previously reported test times for MF-procedures. Herdman and Staples (2001) reported an average time of 83 minutes, three times longer than the 21 minutes for Perez-Abalo *et al.* (2001), while Swanepoel (2001) reports test times between 15 and 31 minutes. It is also relevant to note that Perez-Abalo *et al* and Swanepoel both tested normal hearing subjects, and that Herdman and Staples used 5-dB increments to determine threshold. Testing during the present study took an average of 84.14 minutes, but there are no standards governing the number of sweeps and averages obtained and it would, therefore, be invalid to directly compare present test times with those reported previously. Stimulation at a low intensity increases the number of averages required and, thus, 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 of the audiologist on averaging, the MF-technique allowed the number of sweeps and averages to be selected indicating that the need for objectivity is better met with 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, meaning 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 500 to 4 000 Hz. A level of 100 dB, while possibly suitable for higher frequencies, would have been hazardously 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 500 Hz separately. This partially accounts for the longer times required for MF-testing.

Table 3.6d shows the mean differences between SF- and MF-thresholds and their levels of significance.

Table 3.6d

Differences in sensitivity between SF and MF stimulation techniques

Stimulation technique	Mean difference between ASSR and PT thresholds		
	500 Hz	500 Hz	1 000 Hz
	Left	Right	Right
Single-frequency (Audera)	7,69	8,39	6,13
Multi-frequency (Biologic)	11,71	16,66	8,92
t-test	-1,85 p=0,0694	-3,34 p=0,0014	-1,83 p=0,072

From the table it can be seen that SF-testing yielded more accurate estimates of threshold than the MF-method, particularly at the low frequencies. The SF-technique's better sensitivity may be attributable to the high stimulation levels required, as mentioned previously. Lins and Picton (2000) found no significant differences in response amplitude between 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.

3.7 Effect of stimulation rate

Twenty eight subjects were tested using a 40 Hz stimulation rate (Audera-awake protocol), while 52 subjects underwent testing with the higher rate of 80-110 Hz (Audera asleep protocol and Biologic MASTER). The average testing time (normalised for the number of frequencies evaluated) was 20 minutes longer with the 80-110 Hz stimulation rate than with a rate of 40Hz, but there was no statistical evidence to indicate any difference in the accuracy of threshold determinations between the two (Table 3.6a).

Staples *et al.* 1984 found the amplitude of AEP responses to be two-to-three times greater with a 40 Hz stimulation rate than with a 10 Hz rate. Dobie and Wilson (1998) also found 40 Hz to be the stimulation rate of choice for alert or sedated adults. Rickards and de Vidi (1995) found the 40 Hz rate more suitable for adults, as it requires no compensation or allowance for maturational effects. Researchers have investigated the use of other stimulation rates to overcome the effect of wakefulness on the 40 Hz response (Herdman and Stapells 2001, Lins *et al.* 1995). Difficult-to-test populations are characteristically young children and infants, which may help to explain the move towards higher stimulation rates that are less affected by sleep, sedation and maturation.

3.8 Effect of sedation on SF-and MF-results.

28 non-sedated subjects were tested using the SF-method, while 13 were tested by the same method while sedated. For MF-ASSR tests, 20 subjects were sedated and an equal number were not, to determine the effect of this factor on sensitivity and test time. For both SF- and MF-testing, no significant difference was found between test times for sedated and non-sedated subjects, as indicated in Table 3.8a.

Table 3.8a

Significance of differences in MF- and SF-test time with and without sedation.

Technique	t-test	p value
Single-frequency (Audera)	1,86	0,19
Multi-frequency (Biologic)	2,18	0,15

The same lack of significant differences was found if attention was focused on the threshold estimation accuracy of the SF-and MF- techniques when they were compared for sensitivity with and without sedation, as can be seen in Tables 3.8b and 3.8c.

Table 3.8b.

Significance of sensitivity differences in SF-ASSR testing for sedated and non-sedated subjects

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 3.8c

Significance of sensitivity differences in MF-ASSR testing for sedated and non-sedated subjects.

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 preceding tables indicate no significant effect from sedation on the sensitivity or test time for SF-and MF-testing and, hence, there is no reason to sedate adults, provided that they cooperate and limit their movement during test procedures. Furthermore, other researchers have found that sedation significantly diminishes the amplitude of the 40 Hz response in children (Lins *et al.* 1995). Because sedation does not significantly affect test time or the accuracy of thresholds where the clinician has obtained the necessary cooperation from the subject and it may diminish response amplitude, the ethical and medical constraints should preclude the use of sedation.

Findings of the present study with regard to the objectives can be summarised as:

- ? ASSR testing offers an accurate and reliable alternative to pure-tone methods for estimating thresholds for adult mineworkers with NIHL. On average, ASSR-based thresholds were within the 10 dB variance accepted for reliable results. As with many previous studies, it was found that accuracy was least at 500 Hz.
- ? Contrary to previous findings, the SF-monotic technique was found to be more time-efficient than the MF-method, and also yielded more accurate threshold estimates at 500 Hz.
- ? The traditional 40 Hz modulation rate proved to be more time-efficient than the 80-110Hz rate modulation the population considered.

- ? Sedation did not improve sensitivity or reduce test time for SF-or MF-methods and, hence, no case can be made for using it if the necessary cooperation can be acquired.

These findings for the normative group of 81 subjects provided the basis for determining the clinical value of ASSR methods for evaluating pseudohypacusic mineworkers with NIHL.

3.9 ASSR testing of pseudohypacusic mineworkers

3.9.1 Revision of procedures for experimental group

The 29 subjects in the experimental group (pseudohypacusic) were tested using ASSR methods, specifically the SF-technique with a modulation rate of 40 Hz. Although findings for the normative group indicated that sedation did not improve sensitivity or reduce test times for cooperative subjects, common experience with pseudohypacusic workers, who may be motivated by prospects for NIHL compensation, led to a decision to use sedation for the study group. A second variation in procedures from those used for normative 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, which occurred during normative testing.

3.9.2 Clinical value of ASSRs.

The aim of the present research was to determine if ASSR testing could successfully complete audiological assessment procedures for pseudohypacusic mineworkers. The inability of conventional procedures to provide accurate thresholds for difficult-to-test individuals who are often uncooperative, commonly leads to the repetition of screening and diagnostic procedures and referral to an ENT specialist in efforts to resolve possible compensation cases. Very often, expensive and time-consuming ABR testing is recommended. This provides limited threshold information in the 2 000-4000 Hz frequency range, but otherwise only confirms the presence of pseudohypacusis without determining the thresholds needed for compensation claim or 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.

Of the 29 pseudohypacusic subjects, 28 (96,5%) could be successfully diagnosed and concluded on the basis of ASSR results. In only one case did ASSR testing fail to provide hearing thresholds, and this was in one ear only, due to excessive EEG activity that was

unrelated to the subject's hearing. These results give overwhelming support for the use of ASSR testing as a valid method to estimate hearing thresholds for pseudohypacusic mineworkers with NIHL.

3.10 Further analysis of findings

It was found that 10,3 per cent (3) of the left ears and 17,2 per cent (5) of the right ears (5 people) tested had normal hearing. Audiologists assessing pseudohypacusic workers must be aware of the 80 per cent likelihood that pseudohypacusic individuals will be hearing-impaired, and failure to confirm a diagnosis may have moral as well as health and safety implications in such cases. Although 82,8 per cent of subjects had abnormal hearing, only 48,3 per cent were compensable, indicating that determination of all thresholds necessary for compensation assessments makes differential diagnosis possible, such as in cases of unilateral hearing loss not attributable to noise exposure.

20,7 per cent of the pseudohypacusic subjects were found to be unfit for their present duties, based on current guidelines for safe allocation of workers. This means that the workers' hearing was impaired to the extent that they would not be able to hear danger signals. By failing 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, as well as a likely negative impact on productivity. In this respect, accurate once-off threshold estimations using ASSR methods would be beneficial.

Less than half (48,3 percent) of 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 as a result of workers manipulating their test results over several years. However, a more worrying prospect is that of a sudden deterioration in hearing, which will invariably progress to compensable levels. In examining subjects' previous screening results, it was found that 31 per cent showed signs of sudden deterioration not attributable to noise exposure and warranting further medical investigation. These workers were referred to the OMPs and to the consulting Ear , nose and throat specialist.

3.11 Time required for ASSR testing.

After an average time of 8,1 minutes for skin cleaning/preparation and placing electrodes, an average of 49,9 minutes was required to obtain 10 thresholds (5 test frequencies per ear) in the experimental group. This indicates that one hour would be needed for each ASSR test (10 thresholds), making it a lengthy procedure than pure tone methods (2 thresholds) but providing more essential information. ASSR also provides more information than ABR testing in the same time period.

In comparing these test times with those for normative subjects (average 50,4 minutes), it does not appear that the use of a single room for the audiologist and experimental subjects (as opposed to a separate test booth in the normative group) made any appreciable difference to test time. Nevertheless, it is recommended that a single room without a test booth be used, to discourage deliberate movement and other sources of noise from uncooperative patients.

3.12 Costing

It is difficult to arrive at an accurate and universally applicable formula for evaluating the financial impact of pseudohypacusis on the mining industry. Begley (2003) stated, *"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."*

It is also 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 author and other audiologists consulting to the industry have noted an escalation of apparently erroneous compensation or overcompensation of pseudohypacusic individuals, particularly after 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 DeVidi (1995) found that individuals who had been compensated exaggerated their hearing loss by an average of 12,2 per cent.

With cognisance of the preceding points, the potential cost of pseudohypacusis is analysed considering the following components:

- ? Lost production
- ? Lost shifts
- ? Transport costs
- ? Specialist referrals
- ? Overcompensation

Lost production

Lost production can be estimated is as follows (Geyser 2003):

A 30-metre panel being 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 single operator's absence might not have a direct impact on production, because of multi-skilling in teams. Thus the loss of production has not been used in the calculations due to the mentioned short-comings in such a calculation.

Lost shifts

A rockdrill operator, normally classified as Category 4, earns an average monthly wage of R 2 260 per month, or R 113 per day.

Transport costs

Transporting workers to Occupational Health Centres, hospitals and clinics carries a cost of 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, indicating a cost of R 120,68 per worker.

Estimated Costs of ASSR

Lost shift	R113.00
Transport	R120.68
ASSR test (Taken as equal to ABR costing)	R503.36
Total cost:	<u>R 737.04</u>

Specialist referrals (current scenario)

(a) Second referral for audiology

A worker may be referred for a second audiological evaluation if thresholds have not been determined during the first diagnostic evaluation. Costs can be calculated as follows:

Lost shift			R113.00
Transport:			R120.68
Audiology:			
Consultation	82012	R82.30 (BHF tariffs)	
Air conduction audiogram	82013	37.20	
Bone conduction audiogram	82015	37.20	
Tympanometry	82021	37.20	
Reflexes	82022	37.20	
Total cost (audiology)			R231.10
Total cost:			<u>R 464.78</u>

(b) ENT referral

If the audiologist's second attempt to determine thresholds is unsuccessful, the worker is often referred to an ENT specialist, involving the following costs:

Lost shift			R113.00
Transport			R120.68
ENT consultation (0141)			R113.40

The ENT specialist will be unable to finalise the diagnosis without a reliable audiogram, and it may be necessary to repeat audiological procedures.

			R231.10
Total cost			<u>R 578.18</u>

(c) ABR testing

If the ENT specialist is still unable to make a final diagnosis and determine hearing thresholds, an ABR may be requested, involving the following costs:

Lost shift			R113.00
Transport costs			R120.68
ABR (2692)			R503.36
Revisit ENT			R113.40
Total cost			<u>R 850.44</u>
TOTAL COST (a+b+c)			R1893.40

These costs indicate that without considering the effect of any overcompensation and loss in production, the cost of assessing a pseudohypacusic worker can amount to R1893.40. After all these costs have been incurred frequently pure-tone thresholds have still not been determined across the frequency range and, thus, the case remains unresolved. This compares with an estimated cost of R737 for ASSR testing.

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 conservative estimate), it implies that 253 workers cost the employer R 479 030 in unnecessary diagnostic evaluations.

Considered in this light, the R 220 000 cost for an ASSR test system (HASS December 2002) 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 NIHL cases to be finalised effectively, serving the interests of both the employer and deserving workers.

Overcompensation

The literature indicates that between nine and 33 per cent of workers with prospects of claiming compensation exaggerate their hearing losses. Haughton *et al.* (1979) showed that it is possible to consistently exaggerate a hearing loss within six dB (nine per cent). It is thus quite possible for an audiologist to overlook this amount of exaggeration (within 10 dB).

The average compensation settlement for NIHL 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 (which would be taken as reliable), it would amount to a total overcompensation amount of R 184 000 (R 8 000 per worker x 23 workers). This is based on the following:

A worker with earnings of R4000 per month (including salary, overtime, holiday allowance and housing) will be compensated an amount of R 12 000 for a permanent disability (PD) of 6 per cent.

This amount is based on

Earnings multiplied by % PD, multiplied by 15 and divided by 30, i.e.

$R\ 4\ 000 \times 6 \times 15 \div 30 = R\ 12\ 000.$

If this worker exaggerated his hearing loss by nine per cent, his %PD would have risen to 10 per cent, with the following effect:

$$R\ 4\ 000 \times 10 \times 15 \div 30 = R\ 20\ 000, \text{ i.e. an overcompensation of R } 8\ 000.$$

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, per cent permanent disability. Nevertheless, this exercise demonstrates that the use of truly objective methods for assessing NIHL in pseudohypacusis workers would yield considerable cost savings.

4 Conclusions and recommendations.

Mineworkers who have noise-induced hearing loss and believe that they may qualify for financial compensation commonly present as uncooperative patients, as evident from apparent efforts to confound assessment procedures or exaggerate their hearing loss. Such instances of pseudohypacusis became far more prevalent after implementation of WCC Instruction 168 in 1995. In addition to the financial impact on employers from fallacious claims and overcompensation, the number of pending cases escalates, impeding efforts to finalise genuine claims for NIHL. In many instances follow-up diagnostic procedures also fail to provide the accurate hearing thresholds needed to finalise a claim, putting the clinician in a position of having to make debatable recommendations with regard to rehabilitation, fitness for work and compensation. This increased incidence of pseudohypacusis has had the following consequences:

- ? Frustration on the part of audiologists and occupational health personnel, and mistrust on the part of workers, with retesting and counselling failing to make a difference in eliciting their cooperation.
- ? Escalating costs for audiological assessments, often without a successful diagnosis other than confirmation of pseudohypacusis.
- ? Greater numbers of specialist referrals due to the failure of current audiological procedures to finalise cases, including many that have been referred previously and remain inconclusive due to lack of patient cooperation.
- ? Claims from workers who genuinely deserve to be compensated are not settled due to unmanageable caseloads.
- ? Workers with normal hearing have been compensated.

- ? Workers with severe hearing loss who should have been declared unfit for work in noisy areas have been further exposed to the detriment of their remaining hearing and quality of life, as well as to their safety and that of their fellow workers.
- ? Cases of sudden onset of hearing loss and ear pathology have been overlooked or misdiagnosed, due to the failure to obtain hearing thresholds, as well as lack of worker cooperation.

ASSR test methods were clinically evaluated by means of an experimental study of their accuracy, objectivity, practicability and cost in assessing noise-induced hearing loss in pseudohypacusic workers. The findings indicate overwhelming support for the use of ASSR methods as a more reliable alternative to pure-tone testing of adults with NIHL, and that they can serve as a once-off procedure to finalise the diagnosis and management of pseudohypacusic workers. ASSR results met requirements for accurate thresholds at all frequencies required for compensation and fitness-for-work evaluations.

The procedure proved to be lengthier than the normal battery of diagnostic tests, approximately 60 minutes including preparation time, compared with the 17 minutes typically required for pure-tone audiometry, otoscopic examination and immittance measurements (tympanometry and auditory reflex testing). This is to be expected for electrophysiological procedures, which are more costly than conventional methods, but savings from the elimination of lost production time and unnecessary re-evaluations should quickly offset the cost of testing, even without considering the financial impact of overcompensation and unresolved claims. ASSR testing compares very favourable with ABR testing in time spent on the procedure but ASSR techniques estimate 10 thresholds in the 60 minutes where ABR testing only estimates two thresholds.

ASSR testing proved to be accurate in assessing hearing losses that ranged from normal to profound, and showed no influence from the age of subjects, in accordance with previous research. Given that ASSR procedures can take longer in the presence of background EEG noise, the effect of sedation was evaluated and found to have no significant influence on the sensitivity or time-efficiency. This was a welcome and valuable result, in view of the ethical and medical constraints to the use of sedation.

The SF-ASSR procedure proved to be the method of choice for pseudohypacusic patients with NIHL, due to the robustness of the 40 Hz response, and the fact that it eliminated any need to expose subjects to high-intensity stimulation at test frequencies. This is not the

case for the MF-ASSR procedure, which has no algorithms to compensate for the greater thresholds at higher frequencies typical of SNHL. SF-testing also allowed for manual control of stimulus intensity, allowing the level to be adjusted where a response could not be obtained as is done with conventional pure-tone tests.

Based on present findings for pseudohypacusic mineworkers with NIHL, recommendations are made for the implementation of ASSR testing to better enhance:

- ? Diagnostic evaluations.
- ? Appropriate recommendations for rehabilitation.
- ? Fitness-for-work assessments.
- ? Compensation evaluations.
- ? Specialist referrals.

Limitations of ASSR methods and of the present study that should be addressed include:

- ? The present study provided no indication of inter-test repeatability, because the need to avoid interference with production schedules precluded any repetition of the lengthy testing procedures by a second clinician.
- ? The present study provides no indication of any gender influences because all subjects were males, consistent with the current population of mineworkers at the host mine and across the industry.
- ? The influence of patient-generated noise on electrophysiological techniques is an ongoing clinical concern. Artefacts from high levels of background EEG activity can lengthen the procedure and there is a lack of standardisation for the testing environment, patient instructions and permissible number of artefacts. These should be specified on the basis of current knowledge and published, to enable inter-study comparisons and further refinement of ASSR techniques.
- ? Standards are also 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.
- ? In selecting experimental subjects with noise-induced hearing loss, it was stated that subjects had sensorineural hearing loss. The “neural” aspect was not investigated to determine, for example, any influence of retro-cochlear pathology. It is therefore recommended that a clinical study be made using ASSR methods in

combination with click ABR testing, to allow differential diagnoses which are not possible with ASSRs alone.

- ? The current study has not considered the possible influence of human immunodeficiency virus (HIV). The high incidence of HIV/AIDS among mineworkers is well known, and it has also been shown that that up to 33 per cent of HIV-infected patients suffer from relevant disease – middle ear, inner ear and CNS manifestations (Chandrasekhar, Connelly, Bralmbhatt, Shah, Kloser and Baredes 2000). This indicates a need for further research to determine the influence of HIV on ASSR results. Bainkaitis and Keith (1995) note that HIV has been shown to induce neuro-pathological changes, particularly subcortical demyelisation, even in the absence of overt neurological manifestations. 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 NIHL compensation is compounded by audiological changes due to HIV infection or its complications.

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 are also treated with various combinations of ototoxic drugs for the treatment of tuberculosis and HIV-related manifestations. This points to a need for investigation of the contribution of HIV to hearing problems among mineworkers, and the development of the means for the differential diagnosis of multi-factor hearing loss.

The present study did not evaluate late cortical evoked response (CER) accuracy in estimating hearing thresholds for pseudohypacusic patients. This procedure has been used in Australia for more than 20 years, but the present study was impeded in this regard, since the technique is not used in South Africa and, hence, the equipment is not readily available. Furthermore, the clinical skill and knowledge required of the clinician play a major role in applying CER methods, and it was agreed that a totally objective procedure would be preferable. However, future investigations could well be directed at evaluating this method of audiological assessment.

In conclusion, ASSR testing, particularly the SF-method offers an objective and accurate means of determining hearing thresholds for pseudohypacusic mineworkers. This method of testing also offers the option of using 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 with pure-tone clicks and tone bursts.)

Implementation of this new technique in the South African mining industry will depend on approval from the Workmen's Compensation Commissioner and Rand Mutual Assurance in order for it to be used for compensation purposes. It is also recommended that audiologists consulting to the mining industry be trained and accredited for efficient and competent use of this new threshold estimation technique.

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Appendix A: Case History (research questionnaire)

ASSR Research questionnaire

Ind no. _____

Study no. _____

Date _____

Date of birth _____

Mine _____

Audiologist _____

1. **Otoscopy**

<u>Landmarks</u>	L	R	<u>Cerumen</u>	L	R
Cone of light	_____	_____	Occluding	_____	_____
			Minimal	_____	_____
			Excessive	_____	_____
			None	_____	_____

<u>Tympanic Membrane</u>	L	R	<u>External canal</u>	L	R
Normal	_____	_____	Normal	_____	_____
Dull	_____	_____	Red/Swollen	_____	_____
Perforated	_____	_____	Foreign body	_____	_____
Scarring	_____	_____	Growth	_____	_____
			Drainage	_____	_____
			Blood	_____	_____
			Collapsed	_____	_____

2. **Immittance measurements**

	L	R
Compliance	_____	_____
Volume	_____	_____
Pressure	_____	_____
Reflex ipsilateral 1000Hz	_____	_____

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

Description	Date	L ear					R ear				
		.5	1	2	3	4	.5	1	2	3	4
ASSR threshold											
Pure tone threshold											