CHAPTER 1

INTRODUCTION

AIM

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

1.1 BACKGROUND

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

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

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

1.2 RATIONALE

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

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

---

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

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

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

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

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

Rickards, de Vidi and McMahon (1996) have examined the financial impact of pseudohypacusis, citing Australian studies that report the incidence of pseudohypacusis to be between nine and 30 per cent among workers tested for compensation purposes. The same authors found that individual workers exaggerated their hearing loss by 12,2 per cent, on average, concluding that undetected exaggeration of hearing loss can lead to substantial increases in compensation payouts and, hence, in employers' costs for insuring their companies against the risk of noise-induced hearing loss. Rickards and De Vidi (1995) estimate that overcompensation to an average amount per claim of A$ 7 357, amounting to A$ 12m per year, is awarded to workers with exaggerated hearing loss in Australia. The South African mining industry, with its much larger workforce and greater pressures on profitability (Franz, 2003) can ill afford such a waste of financial resources.

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

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

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

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

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

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

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

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

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

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

1.3 PROBLEM STATEMENT

From the above discussion, it is clear that current audiological procedures (behavioural and electrophysiological) cannot provide all the specified thresholds for determining fitness and compensability (Workmen's Compensation Commissioner, 1995). It is necessary to search for some solution that can address all the needs related to diagnostic audiology in the mining industry in South Africa.

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

1.4 PROPOSED SOLUTION

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

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

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

A novel auditory evoked potential technique known as auditory steady state responses (ASSRs) was discovered and developed in Australia at the University of Melbourne during the 1980s (ERA Systems, 2000). This technique addresses the main shortcomings of ABR testing, in that it does not suffer from the spectral distortion problems associated with short-duration stimuli (Rance *et al.,* 1995). ASSRs are periodic scalp potentials arising in response to regularly varying stimuli, such as amplitude and/or frequency modulated tones (Rance *et al.,* 1998).

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

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

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

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

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

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

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

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

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

1.5 PURPOSE OF THE STUDY

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

1.6 CLARIFICATION OF TERMINOLOGY

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

1.6.1 AUDITORY EVOKED POTENTIAL (AEP)

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

1.6.2 AUDITORY STEADY STATE RESPONSE (ASSR)

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

1.6.3 NOISE-INDUCED HEARING LOSS (NIHL)

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

1.6.4 PSEUDOHYPACUSIS

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

1.7 OUTLINE OF THE STUDY

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

- **CHAPTER 1: INTRODUCTION**

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

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

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

The phenomenon of pseudohypacusis is discussed to enable the research question to be addressed. Pseudohypacusis is defined, and the reader is familiarised with the acronyms used in the relevant literature. The prevalence of and etiological factors involved in pseudohypacusis are discussed concurrently, since prevalence is closely linked to motivating factors.

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

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

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

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

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

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

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

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

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

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

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

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

- **CHAPTER 5: RESEARCH METHODS**

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

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

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

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

- **CHAPTER 6: RESULTS**

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

This study proves that ASSR testing is sensitive enough to estimate behavioural thresholds in a population of mine workers with abnormal and noise-induced hearing loss, and that, if workers exaggerate their hearing loss, ASSRs can estimate the true thresholds and thus conclude the diagnostic procedures with the correct recommendations regarding the fitness, compensability and further handling of the patient.

- **CHAPTER 7: CONCLUSIONS AND RECOMMENDATIONS**

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

1.8 SUMMARY

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