Chapter 1
Introduction

1.1 Background

"Excessive noise is a global occupational health hazard with considerable social and physiological impacts, including noise-induced hearing loss (NIHL). Worldwide, 16% of the disabling hearing loss in adults is attributed to occupational noise." (Nelson, Nelson, Concha-Barrientos, & Fingerhut, 2005;446)

An occupational audiologist specialises in the prevention of NIHL, while working in an industrial environment and provides critical input if determination of compensation for NIHL becomes necessary (ASHA, 1996). In the South African context, this is especially so, because financial compensation paid to occupationally hearing impaired workers, is based on diagnostic audiological testing and actuarially designed tables (DME, 2003).

1.2 History of Audiology in South Africa

Audiology as a profession in South Africa has evolved over the past 70 years from a combined profession of speech and hearing therapy into two interlinked but independent professions of audiology and speech therapy (Hugo, 2004; Swanepoel, 2006). Both of these professions were introduced to South Africa by the Hamburg-trained logopaedician, Pierre de Villiers Pienaar. He established the first programme that trained therapists in Logopaedics in 1938 at the University of the Witwatersrand, Johannesburg (Aron, 1973). The course had expanded from a two-year diploma to a four-year degree by 1948, and Pienaar also initiated the training programme at the University of Pretoria in 1959 (Hugo, 2004; Swanepoel, 2006). Audiology was taught as a separate course in the degree in 1962 (Aron, 1973).

The transformation of the profession has been partly in response to the rapid technological developments in testing and rehabilitation practices, which have required more intensive training in specialised fields, and partly due to international trends, where there are two distinctive professions that are specialist rather than generalist (Swanepoel, 2006; Uys & Hugo, 1997). The political changes that have taken place in South Africa since the introduction of democracy in 1994 have further spurred on the transformation in the models of practice and training of professionals, influenced by changes in welfare, health and education policy (Swanepoel, 2006). Changes in training and the influence of the changes in the political climate have increased the awareness of: worker rights, occupational disease and injury and, in particular, the impact of noise on workers and subsequently compensation claims (HPCSA, 2008b; Leger & Nicol, 1992). These factors have resulted in a progressive increase in the emphasis on occupational audiology in the training of audiologists.

1.3 History of Occupational Audiology

In the United States (US) the military audiologist was at the forefront of the development of occupational audiology as early as the 1940s in response to hearing loss developed by soldiers and military personnel in World Wars I and II. Legislation enforcing hearing conservation programmes in the US was implemented in the 1960s, with regular improvements being made, often as a result of lobbying from American Speech and Hearing Association (ASHA) members, ensuring that occupational audiologists have a pivotal role in the prevention of hearing loss (ASHA, 1996). ASHA published a position statement in 1996 on the role of the audiologist in Occupational and Environmental Hearing Conservation, in which the underlying premise for the role of the occupational audiologist is motivated as follows:

> "Audiologists with a strong background in all aspects of audiometric monitoring and interpretation of audiograms, equipment calibration, hearing

> conservation and rehabilitation and noise measurement can offer appropriate guidance and leadership in the development of occupational Hearing Conservation Programmes (HCPs) and in the interaction of professional disciplines which include occupational medicine, industrial hygiene, engineering and safety.” (ASHA, 1996:16)

The position statement highlights the need for audiologists to take a leading role in hearing conservation planning as well as the need for standards for service delivery and professional conduct in this arena. US legislation requires the professional supervision and audit of audiometry results for an industry by an accredited audiologist. Accredited audiologists are also required to record statistics of occupational hearing loss (ACOEM, 2002). The US occupational audiologist is also intimately involved in the determination of the extent of work-relatedness of a hearing loss, since compensation legislation requires percentages of hearing loss due to work and those due to non-work-related causes to be apportioned according to standard formulae (Dobie, 2001). Guidelines for hearing conservation recommend that the US occupational audiologist conduct approved training courses and refresher courses for technicians (ACOEM, 2002). International legislation entrenches the occupational audiologist in the process of the prevention of NIHL (EU, 2003; MSHA, 1999; NZDOL, 2002).

In comparison with the development of occupational audiology in other parts of the world, in the South African context, the role of the occupational audiologist is less specific and the occupational audiologist usually has no, or a very small, role in hearing conservation practices. The South African legislation that governs occupational injuries and disease, and their compensation, is two-fold:

- firstly, Schedule 3 of the Compensation for Occupational Injuries and Diseases Act (COIDA), known as Instruction 171; and
- secondly, the Mine Health and Safety Act (MHSA) (DME, 1999; DME, 2003) when the worker works in mining, and the Occupational Health

and Safety Act (OHSA) if working in industries other than mining (DOL, 1993).

In the South African context, the legislation pertaining to acoustic measurements within a working environment, as well as the legislation pertaining to baseline hearing testing and annual monitoring of hearing, have been derived from the Department of Minerals and Energy (DME) guidelines for the compilation of a mandatory Code of Practice for noise (DME, 2003). These legal enforcers of the prevention of NIHL only include the audiologist in the capacity of obtaining a diagnostic audiogram for compensation purposes. In no other areas would one find mention of audiologists or their expertise as the designated specialists who should be guiding the process of prevention.

Approximately 1800 professionals are registered as speech therapists and/or audiologists with the Health Professionals Council of South Africa (HPCSA) (HPCSA, 2008a). Approximately 470 000 miners are insured for occupational injuries and diseases with the Compensation Commissioner (Begley, 2004; DME, 2007; Hermanus, 2007). The high ratio of workers to professionals is evidence of the need for more trained professionals in the mining sector alone, as well as evidence of the shortage of sufficiently experienced occupational audiologists for fully participating in the medico-legal process of NIHL compensation. The need is even greater when the whole South African workforce, other than mining, is taken into account.

Legislation governing NIHL prevention was first enforced in South Africa in 1996 and recent revisions to this legislation are evidence of the growing attention by government to the safety and health needs of workers. Owing to the enforcing of legislation (COIDA, 1993; DME, 2003; Hermanus, 2007) and the large costs resulting from compensation claims, in the mining industry in particular, the role of the audiologist in the occupational health team has increased, especially the role as a member of the medico-legal team that deals with compensation for NIHL claims.

1.4 Mining in South Africa

Mining is an ancient occupation, long recognised as being arduous and liable to injury and disease, and possibly death for the workers. The lifecycle of mining consists of exploration, mine development, mine operation, decommissioning and land rehabilitation. Mining is a multidisciplinary industry, drawing on several professions and trades (Donoghue, 2004). Mining remains one of the most hazardous occupations in the world, both in terms of short-term injuries and fatalities and in terms of long-term impacts such as cancers and respiratory conditions, e.g. silicosis, asbestosis and pneumoconiosis, and NIHL because dust and noise are inherently associated with rock breaking (Hermanus, 2007; Stephens & Ahern, 2001).

South Africa is a mining nation with rich mineral resources, with gold and other minerals being the largest single source of foreign exchange (34 per cent of the value of exports) and formal employment (6.5 per cent) (Hermanus, 2007). Some of the differences between South Africa and other major mining countries are: the depth of gold mines, the labour intensiveness of gold and platinum mining, and the large number of workers on a single mine, which present significant organisational and logistical challenges.

The history of mining in South Africa is closely linked to the political history. During the apartheid era, certain job categories were reserved for people of colour and little emphasis was put on the health and safety of workers in general (Leger & Nicol, 1992). The result was that the workforce in the South African mining industry was largely made up of black men and that legislation to protect workers' hearing was slow to be implemented (Leger & Nicol, 1992; Myers & Macun, 1989).

The new political era in the country after 1994 resulted in the appointment of the Leon Commission of inquiry into safety and health in the mining industry, whose recommendations were promulgated as the Mine Health and Safety Act (MHSA) of 1996 (DME, 1996; Stanton, 2003). The Act instituted The Mine Health and Safety Inspectorate, which is responsible for safeguarding the health and safety of people working at mines or affected by mining activities.

The Mine Health and Safety Council (MHSC) of South Africa has set targets for the mining industry of no Percentage Loss of Hearing (PLH) greater than 10% by 2008 and no machinery emitting noise levels of greater than 110 dBA by 2013. The targets are an attempt to improve the prevention of NIHL in the mining industry and are based on current statistics that 67% (or 209 666 people) of South African mineworkers are exposed to noise levels of 85 – 105 dBA ($TWA8_h$) and that, between 1998 and 2003, R448 million was paid out in NIHL compensation claims (Hermanus, 2006).

1.5 Nature of Occupational Audiology in the South African mining industry

The reasons for pursuing the current study were developed during the researcher's employment as an in-house occupational audiologist at a gold mine in the North West province in South Africa. Clinical experience in that situation revealed that current South African mining testing practices combined with the actuarial tables used to determine an individual miner's compensation, might not be the most accurate or fairest determination of compensation for NIHL. Initial clinical impressions that evolved into the rationale for the study are summarised in table 1. These characteristics are discussed in more detail in the subsequent sections.

Table 1 Initial impressions of the characteristics of the audiological caseload in the mining industry.

Characteristic	Result	Potential solution
Language differences between audiologists and clients	Results in difficulties communicating concepts for testing and understanding instructions	Objective measure
Beliefs/myths about hearing loss among the clients	Resulted in high incidence of pseudohypacusis	Objective measure
Calculation of Percentage Loss of Hearing for compensation purposes	Weighting of frequencies appeared skewed	Increased number of frequencies measured with DPOAE
Configuration of DPOAE mimicked the audiogram configuration	Apparent ability of DPOAE to predict audiogram	Predictive model of audiogram from DPOAE

1.5.1 Language differences

One characteristic in the adult male mining population was related to differences in the language and the culture of the clients from those of the occupational audiologists. The South African population and in particular the mining workforce, is made up of developed and developing sections comprising many cultures and languages, evidenced by the 11 official languages in South Africa (Statistics South Africa, 2003; Swanepoel, 2006). The many languages spoken in the country, and the lack of understanding of all the languages by the audiologist or the person being tested impact on the testing process. In the mining environment, the audiologist's ability to communicate concepts, for example the concept of "threshold of hearing", and to conduct basic testing to evaluate speech perception abilities is limited by their ability to communicate in the client's language as well as by the client's ability to understand the purpose of testing and the instructions given for testing. The constraints can negatively influence the reliability of the test results.

1.5.2 Pseudohypacusis

Another characteristic of the caseload in the mining environment is that of beliefs or myths within the organisational culture. One such anecdotally reported belief among miners is that being "deaf" means that one has worked for a long time in the mine and that one is therefore strong and can demand respect from fellow workers. The peer pressure of needing to present one's hearing loss as worse than it really is as a result of this belief, may be the reason for the many cases of pseudohypacusis (feigning a hearing loss) encountered in the mining industry although not previously documented in sociological literature.

Another such belief, also anecdotal and encountered in clinical practice and not documented in any known research, is that one does not speak quietly, since that would imply that one is speaking about someone behind their back. The fact that this belief results in a noisy environment and a rejection of quiet sounds, can impact on a miner's perception of "the softest sound you can hear" or "threshold" and this negatively impacts the response accuracy resulting in inflated thresholds.

These characteristics of the caseload encountered in the mining industry imply that the South African occupational audiologist needs to be aware of the contextual influences on testing to ensure that the final diagnosis is accurate. The need for the audiologist to have extensive experience in occupational audiology is that the aforementioned beliefs result in a high incidence of pseudohypacusis as a confounding issue in clinical testing and compensation claims (Balatsouras et al., 2003; Schlauch, et al., 1996).

The researcher's clinical experience in the mining setting seemed to indicate that the pseudohypacusis encountered appears to be unique. The uniqueness is partly the result of the staff profile in many occupational audiology environments in South Africa, where there is a predominance of white, female audiologists. The clients in these clinical settings are predominantly black males who are in many cases unskilled labourers. This is as a result of the political history of South Africa, in particular the labour segregation that took place in the mining industry during the apartheid era (Leger & Nicol, 1992). This has a negative effect on the social interaction and communication in a clinical setting. The history of negative attitudes towards people of different races because of apartheid and the influences of how males and females interact in different cultures also negatively influence the audiologist's ability to establish accurate hearing threshold levels. The skills of the audiologist are often challenged by the complex, historical and political nuances that affect the South African society (Johnstone, 1976). Consequently, the need arose to explore models of practice that used objective measure of hearing loss that is clinically useful and reliable, and that will provide a cross-check of results as well as results that are fairer to both the claimant and the company paying the compensation (Balatsouras, Kaberos, Korres, Kandiloros, Ferekidis, Economou, 2003; Qiu, Yin, Stucker, Welsh. 1998).

1.5.3 Percentage Loss of Hearing

The researcher's clinical experience with the calculation of PLH further contributed to the development of a rationale for the current study. The PLH concept is based on the use of the thresholds for the frequencies of 500 Hz, 1000 Hz, 2000 Hz, 3000 Hz and 4000 Hz from both ears to calculate a worker's PLH. The calculation uses actuarially developed tables, which are the basis for the new legislation that came into effect in May 2001, and is used for the management of NIHL prevention and compensation (COIDA, 1993).

Experience in the clinical setting resulted in the weightings used for the different frequencies in the PLH calculation tables, being questioned. The occupational audiologists found that even the smallest of changes in thresholds in the low frequencies resulted in seemingly disproportionately large changes in the PLH calculation. This compared to larger high frequency changes resulting in very small changes in calculated PLH that seemed unfair towards the person receiving compensation. The weighting for the speech frequencies appeared to be too great, while the predicted effect of a high frequency loss appeared to be regarded as less important. The fact that NIHL affects the high frequencies and that the complaint from clients in this population is always one of difficulties with speech recognition in background noise (a high frequency loss symptom) (Vermaas, Edwards & Soer, 2008) raised questions about the fairness of the calculation that ultimately impacted on the amount of compensation that a worker received and the need for a more representative weighting of frequencies was evident.

Further investigation into the origins of the tables and the basis for the weighting on the tables showed that the new legislation had been based on Australian practices for NIHL compensation (Barnes, 2006) . During the promulgation of the new South African legislation for NIHL compensation in 2001, the tables used in the Australian system had been adapted for the South African context because the practice in Australian audiology includes the frequency of 1500 Hz. The South African PLH tables have halved the proportion for 1500Hz and added these weightings to the two closest frequencies, namely 500 Hz and 1000 Hz (Barnes, 2006; Steffens, 2008).

The researcher hypothesised that a possible solution to the apparent "unfair" weighting from the current PLH tables may be found if DPOAE, a more representative test of many more points along the basilar membrane of the cochlea, was used as a basis for the calculation of PLH. The stimulus frequency protocol used in the mine clinic included 11 DPOAE frequencies, this being a more representative evaluation of the eight frequencies usually tested on an audiogram. Also, most commercially available measurement instruments can test up to 22 frequencies providing the potential for an even more in depth evaluation of the cochlear functioning than was currently the case. Although the proposed increased evaluation of more positions on the basilar membrane would not be a measure of a miner's hearing, it would give an indication of anatomical damage resulting in decreased cochlea functioning and may have provided an alternative to current practice.

1.5.4 Objective measures

Distortion product otoacoustic emissions (DPOAEs) are an essential and well-researched part of the audiologist's test battery used in the measurement of cochlear outer hair cell function. There is a well-documented relationship between the behavioural pure tone thresholds and otoacoustic emission measures (Balatsouras, 2004; Chan, Wong, & McPherson, 2004; Delb, Hoppe, Liebel, & Iro, 1999; Dorn, Piskorski, Gorga, Neely, & Keefe, 1999; Duvdevany & Furst, 2007). It, therefore became logical to implement the routine use of DPOAE measurements along with the standard behavioural pure tone and speech audiometric test battery implemented by audiology clinic within the mining environment.

Initially, there were questions regarding the efficacy of replication of measurements as well as specific number of frequencies needed within this unique setting. Over time it was noted that the replicated DPOAE response intensities were very similar to a single DPOAE response intensities. Additionally, the stimulus frequencies utilised over time resulted in three distinct sets of data collected (i.e. f_2 stimulus frequencies 633 – 3233 Hz for replicated and single measurements and; frequencies 593 – 3031 Hz for single measurements). While there is a plethora of peer review and manufacturer literature on stimulus and response variables of DPOAEs there is no current information regarding selection of stimulus frequencies best suited specifically for use with this population. As a consequence, a question arose whether certain stimulus frequencies elicited better emissions than others in a noise-exposed population.

By incorporating DPOAE assessment as an integral part of the occupational hearing testing battery, not only is there an improvement in the speed with which the large caseload could be managed, but it also can provide the audiologist with objective cross-check methods which results in confidence in the results especially when pseudohypacusis was suspected, thus improving the confidence with which compensation claims were submitted and therefore reduce the need for retesting to confirm results. Additionally, sound-treated rooms are readily available directly before or after audiometric testing is conducted.

1.6 Rationale for the study

Most studies showing efficacy of DPOAE measurements have thus far been predominantly in the field of military audiology, but to date only screening and diagnostic techniques in a mining noise-exposed population have been investigated as an indicator of early noise induced hearing loss (De Koker et al., 2003). There is a potential benefit from objective tests which can be strengthened by incorporating a prediction procedure that could solve specific problems encountered in the mining environment. The prediction models reported in the literature have not reported high levels of accuracy nor ease of use but an alternative multivariate proposal has not been tested on a large scale as one would find in the mining environment (Gorga, et al., 2005).

Compensation for NIHL is a very central issue in the South African mining environment, costing employers a great deal of money and requiring a novel approach. The use of DPOAEs that have options of measuring numerous points on the basilar membrane appeared to provide one such novel approach. The research questions that defined the study was: What are the characteristics of DPOAEs in a noise-exposed mining population? Can DPOAEs be used reliably as a predictor of hearing threshold levels and in the long term as an alternative to behavioural audiometry in a population who have existing varying degrees of cochlear damage from noise exposure?

1.7 Potential impact of research outcomes

The impact of the current study is potentially in the fields of equipment development, clinical testing and management of difficult-to-test clients, compensation for NIHL, training of audiologists and models of practice for prevention of NIHL.

Firstly, the predictive model that was developed from the current study can be included in DPOAE testing equipment programmes to facilitate the automatic calculation of a predicted audiogram. This automatic prediction will be necessary since the model has up to five steps and requires complex calculation which would not be easily done manually in a clinical situation.

Secondly, such an automated computer programme will provide the audiologist in a busy practice with tools that will improve the speed and efficiency when managing pseudohypacusis or difficult-to-test clients, by reducing the need for repeated testing. In a mining environment this impacts on the productivity and the safety indicators by reducing the lost-shift statistics. This in turn reduces the costs of mining and improves profits. The audiologist's confidence with which to confront a client about suspicions of lack of co-operation on testing procedures will be increased.

Thirdly, the compensation process for NIHL will be enhanced by the audiologist's ability to provide additional and objective information for the medico-legal process that is involved in compensation. This enhances the role of the audiologist in the field of occupational audiology. The potential impact of the inclusion of the scientific validation of the use of DPOAEs as an integral and required part of the process of NIHL compensation claims is that policies and legislation should be influenced and changed at a national level.

The above three potential impacts of the current research also mean that the training of South African audiologists will need to incorporate the newest and latest findings and thinking with regard to the use of objective tests for NIHL diagnosis and for difficult-to-test populations. The relation between the findings on current practice and tests and the promotion of objective tests such as DPOAEs will form the basis of improved audiology education. The training of audiologists in the details of stimulus frequencies and their impact on test results is also expected to become standard curriculum.

Finally, research outcomes from this study stands to positively impact the field of hearing conservation practice within South Africa and many other countries. The models of prevention currently used in the South African mining environment do not include the use of DPOAEs as standard practice. Some organisations and audiologists use the test but the acknowledgement in legislation and in decision making arena has not taken place as yet. Findings from this study will provide evidence that DPOAEs can become an essential part of the test battery both for pre-employment and ongoing monitoring of noise-exposed workers. Implementation of such a model of practice will enhance the early identification of NIHL and the prevention strategies in hearing conservation programmes both in mining and other industries.

1.8 Organisation of the thesis

Chapter One of this thesis has served as an introductory chapter to the current study, with a brief overview of the history of mining and occupational health issues in South Africa providing the context of the study. Clinical experience provides the background for the rationale for this study.

The subsequent chapter includes a more in-depth discussion of NIHL, with a consideration of the effects of noise on humans, the prevalence of NIHL, the risk of developing NIHL, and the factors that influence the risk. The topics are discussed in terms of the occurrence of NIHL in the South African mining industry, and specific characteristics of the South African gold mining environment are highlighted.

Chapter Three contextualises the study further by discussing the compensation for NIHL from an international perspective, with specific reference to legislation governing compensation. The South African perspective and practice are critically evaluated and the prevalence of NIHL compensation discussed.

The fourth chapter investigates DPOAE characteristics and the value of DPOAEs to the occupational audiologist. The chapter discusses the potential role that this objective test has in the occupational audiology environment by investigating the prediction of hearing thresholds from DPOAE measures.

In the fifth chapter, the thesis provides a discussion of and rationale for the research design used, namely a retrospective record review. The evaluation highlights the strengths and weaknesses of the research design and how they relate to the current study. The research questions asked in the current study are summarised as a conclusion to the chapter.

Chapter Six of the thesis outlines the methodology used by presenting the objectives of the study and the procedures used to conduct the research.

Chapter Seven contains the results of the study. The discussion of the results follows immediately on each result to facilitate clarity of the findings. The prediction model is proposed and validated as part of the results section.

Finally, Chapter Eight concludes with a discussion of the significant findings of the study and with their implications for clinical practice and NIHL prevention policy, as well as for training of occupational audiologists in a developing multicultural and multilingual country.