Otoacoustic emission testing in the early identification of noise-induced hearing loss in South African mineworkers

by

Adele Laura Clark

Submitted in fulfillment of part of the requirements for the degree of Master of Communication Pathology

Faculty of Humanities

Department of Communication Pathology

University of Pretoria

Pretoria

October 2004

Otoacoustic emission testing in the early identification of noise-induced hearing loss in South African mineworkers

by Adele Clark

Study Leader: Ms Maggi Soer

Co-Leader: Dr Catherine van Dijk

Department: Department of Communication Pathology

Degree: Masters in Communication Pathology

Abstract

This study assessed the role of otoacoustic emission screening for the early identification of noise-induced hearing loss in South African mineworkers. Transient otoacoustic emissions and distortion product otoacoustic emissions were recorded in 106 noise exposed mineworkers (212 ears) aged between 20 and 55 years, and in 17 non-exposed novice workers (34 ears) aged between 18 and 29 years. All subjects had normal hearing acuity, otoscopic examinations and immittance measurements. Four otoacoustic emission (OAE) measurements were taken per ear and repeated by a second audiologist for the evaluation of inter-test reliability. Age and number of years of noise exposure was additionally evaluated as well as the specificity and sensitivity of the tests for this population group. In general the OAEs were diminished at four KHz for both the exposed and non-exposed groups. Age was found to be the primary predictor of diminished OAE tracings. Poor inter-test reliability was obtained. These results indicate that further research is required within

this population group before OAE testing can be implemented for screening for noise-induced hearing loss.

Key Words:

Noise exposure, Noise-induced Hearing loss (NIHL), Otoacoustic Emissions (OAEs), Sensitivity, Specificity.

Oto-akoestiese emmisie sifting vir die vroeë identifisering van geraasgeïnduseerde gehoorverliese in Suid-Afrikaanse mynwerkers.

deur Adele Clark

Studie Leier: Ms Maggi Soer

Mede-Leier: Dr Catherine van Dijk

Departement: Departement van Kommunikasiepatologie

Graad: Magister in Kommunikasiepatologie

Abstrak

Die doel van hierdie studie was om die rol van oto-akoestiese emmisie sifting vir die vroeë identifisering van geraasgeïnduseerde gehoorverliese in Suid-Afrikaanse mynwerkers te evalueer. Transiënte oto-akoestiese emmisies and distorsie-produk oto-akoestiese emmisies is vir 106 geraasblootgestelde mynwerkers (212 ore), ouderdom tussen 20 en 55 jaar, en vir 17 non-blootgestelde aanvang werkers (34 ore), ouderdom tussen 18 en 29 jaar, opgeneem. Al die subjekte het normale gehoorsensitiwiteit en immitansie metings gehad. Vier oto-akoestiese (OAE) metings is per oor geneem en deur ‘n tweede oudioloog herhaal vir die evaluering van intertoets betroubaarheid. Addisioneel is die ouderdom en die aantal jare van geraasblootstelling geëvalueer, asook die sensitiewiteit en spesifiekheid van die toetse vir hierdie populasiegroep. Oor die algemeen was die OAE verlaag by vier KHz vir beide die blootgestelde en non-blootgestelde groepe. Daar is gevind dat ouderdom die primêre voorspeller van verlaagde OAE metings was. Swak intertoets betroubaarheid is verkry. Hierdie resultate dui aan dat verdere navorsing benodig word vir hierdie populasiegroep voordat OAE toetsing as sifting vir geraasgeïnduseerde gehoorverliese geïmplimenteer kan word.

SLEUTELWOORDE:

Geraasblootstelling, Geraasgeïnduseerde gehoorverlies, Oto-akoestiese emmisie (OAE), Sensitiwiteit, Spesifiekheid.

Table of Contents

List of Tables:

List of Figures:

List of Appendices:

Abbreviations used in the study:

ACOEM:	American College of Occupational and Environmental Medicine
COIDA:	Compensation for Occupational Injuries and Diseases Act
dB:	Decibels
DPOAEs:	Distortion product otoacoustic emissions
HPDs:	Hearing protection devices
Hz:	Hertz
NIHL:	Noise-induced hearing loss
NIOSH:	National Institute for Occupational Safety and Health
OAE:	Otoacoustic emissions
OHC:	Outer hair cells
SANS:	South African National Standard (SANS, 2004).
SASCOM:	South African Society of Occupational Medicine (SASCOM, 2004).
TEOAEs:	Transient evoked otoacoustic emissions

Preface

With thanks to:

M. Soer

E. de Koker

M Franz and G MacKay

W. de Klerk and Biologic Systems

Troy, Dan and Ben Clark

Chapter 1: Orientation and Description

1. 1 Introduction

People working in noise are affected in a variety of ways. Annoyance, decrease in productivity, psychological distress and physiological changes are only a few of the effects that have been reported (Newby & Popelka, 1985:331; Katz, 1994:536; Guild, Ehlrich, Johnston & Ross, 2001:195). A more direct and permanent consequence is the development of noise-induced hearing loss. Noise-induced hearing loss (NIHL) is referred to as permanent damage, caused by noise, to the outer hair cells of the cochlea resulting in a decrease of the amplification ability of the cochlea (Reshef, Attias & Furst, 1993:387). Noise-induced hearing loss occurs slowly over time, and the full effects are generally realized after 10 to15 years of chronic noise exposure (Rosen, Vrabee & Quinn, 2001:2). The development of noise-induced hearing loss is dependant on the characteristics of the noise, that is, its temporal pattern and spectral distribution, the overall sound level of the noise and the duration of the noise exposure in hours, days, weeks and years (Katz, 1994:537). Exposure to a continuous noise is more damaging than intermittent noise, with sound levels exceeding 75-85 dB(A) beginning to stress the auditory system (Rosen et al., 2001:2; Kvaerner, Engdahl, Arnesen & Mair, 1995:137). It has been estimated that between 68 to 80 percent of mineworkers are exposed to 85 dB(A) or more of continuous noise during their work shift. A shift is averaged at eight hours per day (Guild et al., 2001:195). Mineworkers are therefore significantly at risk for developing noise-induced hearing loss.

Noise is referred to as an intense sound capable of producing damage to the inner ear (Rosen et al., 2001:1). The noise initially causes changes in the biochemistry of the outer hair cells (OHC) of the cochlea, with anatomical changes such as the fusion or disappearance of the hair cells subsequently taking place (Attias & Bresloff, 1996:222; Kemp, 1982:189). The damage to the cochlea typically progresses from a basal to apical direction with the high frequency hearing being affected first. Thus the four KHz notch typical of NIHL is obtained on the audiogram (Arnold, Lonsbury-Martin & Martin, 1999: 217). Conventional hearing test methods such as pure tone audiometry from which an audiogram is obtained, have been traditionally used in screening for NIHL. These methods have fallen short of detecting NIHL sufficiently early in order to prevent NIHL from developing. With the discovery of otoacoustic emissions (OAE's) researchers and clinicians alike have been provided with a new means to evaluate the outer hair cells (OHCs) of the cochlea more accurately and objectively than before (Lonsbury-Martin, McCoy, Whitehead & Martin, 1992:52; Hall, 2000:25). Research is indicating that OAEs have the potential to detect noise damage to the cochlea earlier than pure tone audiometry is able (Kvaerner et al., 1995:140; Attias, Bresloff, Reshef, Horowitz & Furman, 1998:45; Kowalska & Sulkowski, 1997:441; Hall, 2000:325). OAEs are sounds measured in the external ear canal and are generated by and reflect vital biomechanical activity within the normal cochlea (Katz, 1994:448; Lonsbury-Martin et al., 1992:47). Various types of OAEs are obtained, however the majority of research and clinical practice has focused on the use of distortion product OAEs and transient evoked OAEs (Probst, Lonsbury-Martin & Martin, 1991:2043). Animal studies have provided the initial evidence for the production of the OAE being at the level of the OHCs of the cochlea. Animal studies have indicated that a 30 to 50 percent loss of OHC in the apical region of the cochlea which goes undetected by conventional audiometry will be evident on the TEOAE tracings (Arnold et al., 1999:215). The absence or reduction of OAEs occurs as the mechanism for the generation of the OAE, the outer hair cells (OHCs) of the cochlea, becomes damaged (Eddins, Zuskov & Salvi, 1999:120). The OHCs of the cochlea are particularly susceptible to noise damage (Attias & Bresloff, 1996:222; Attias et al., 1998:40). This has implications for possibly evaluating NIHL in a new way as OAE testing assesses the functioning of the OHCs. OAEs as a screening tool for NIHL in industrial hearing conservation programs may therefore become a reality in the near future if proved to be effective and reliable.

Hearing Conservation Programs are implemented in an attempt to detect, manage and primarily, to prevent NIHL (Attias et al., 1998:39). This is important as there is no medical cure once the damage has occurred (Attias et al., 1998:39). If the damaging influences cannot be avoided, then secondary prevention or early identification becomes important (Probst, Harris & Hauser, 1993:85). OAEs may become the means of early identification of NIHL in industry as conventional methods used within hearing conservation programs have only been partially successful in early detection of noise damage (Le Page & Murray, 1998:589). The mining industry has traditionally used pure tone audiometry for evaluating hearing and has developed procedural requirements for testing. A baseline audiometric test is completed before the mineworker commences work, and is then retested periodically for monitoring purposes (Guild et al., 2001:204; SANS, 2004:8). This baseline test forms part of the mineworker's future medical surveillance and service record. In pure tone audiometric testing the subject takes an active part in the test procedure. Motivation and concentration on the part of the subject can thus affect the results. The accuracy of pure tone audiometry in hearing screening programs is also affected by imperfect test conditions such as the use of unskilled testers, functional hearing loss (pseudohypacusis) and familiarity with test procedures over time on the part of the testee (Probst et al., 1993:86). In comparison, OAE testing is objective, noninvasive, rapid and able to provide a repeatable, frequency-specific response (Hall, 2000:27-28). Other than providing objective, immediate and accurate results, OAE testing does not require active participation on behalf of the subject. It does however require a quiet test area and trained testers. OAE results cannot be directly converted into hearing thresholds and a limited frequency region is tested as compared to the audiogram (Hall, 2000:25). Pending further research, no generalized conclusions can be made with regard to the pattern of cochlear dysfunction and the spectrums obtained from the OAE testing (Probst et al., 1991:2048; Bonfils, Piron, Uziel & Pujol, 1988:56). Although OAEs can not be translated into hearing thresholds directly, what has been found in these studies, is that transient otoacoustic emissions (TEOAE's) are measured in all ears with normal hearing, and are always absent in hearing loss exceeding 25 to 35 dBHL (Attias et al., 1998:39; Bonfils et al., 1988:53). In comparison distortion product otoacoustic emissions (DPOAE's) are measured in ears with hearing loss up to 55 dBHL. Otoacoustic emission testing may provide the industrial sector with an alternative to pure tone testing. Researchers have begun to investigate its applicability as a method of early identification of NIHL within this population group (Kvaerner et al., 1995:137; Engdahl & Kemp, 1996:1573; Attias et al., 1998:40). In particular, it may enable the tester to identify early damage to the cochlea and thus ultimately to limit the effects of the hearing loss on the person exposed to noise.

Mineworkers in particular are exposed to damaging levels of noise in their daily work environment. Hearing protection devices are provided, but do not cancel out all noise. Thus damage to the hearing continues to occur. NIHL results in millions being spent nationally as well as internationally, by the industrial sector in compensation and rehabilitation of NIHL. Forty percent of compensation given to South African mineworkers, every year, is for NIHL (Guild et al., 2001:195). When the "percentage loss of hearing" (calculated by combining the hearing thresholds at 500; 1000; 2000; 3000; and 4000 Hz) shifts more than 10 percent, the mineworker qualifies for compensation (Guild et al., 2001:208). NIHL appears initially as a notch or a depressed hearing threshold at four KHz on the audiogram and primarily affects the higher frequency range (three KHz and above). According to the above-mentioned calculation, further decreases in hearing thresholds at the other frequencies are required before the mineworker is deemed to be compensatable. The mineworker will more than likely experience difficulty in his daily communication with others for a period of time before being compensatible. Hearing loss, if only present at the high frequencies, causes difficulties in day to day communication for the person with a hearing loss. In particular, the person may find it difficult to follow conversation in noisy environments (Rosen et al., 2001:3). This can therefore affect their safety and productivity at work, in the noisy environment, and consequently their profitability for the industry (Guild et al., 2001:195). Early identification of noise-induced hearing loss in susceptible individuals will enable appropriate intervention to be implemented and reduce the risk of further impairment as well as long term costs in compensation. Therefore further research is important in the area of NIHL.

Research in the area of OAEs and NIHL has been limited to small groups of subjects, tested within controlled settings. In addition, most studies have exposed the subjects to intermittent or brief-duration noise exposure rather than continuous noise exposure (Eddins et al., 1999:120). This has resulted in insufficient data being available in ears exposed to industrial noise. Thus research concerning OAEs in the area of NIHL has been limited (Kowalska & Sulkowski, 1997:442). TEOAE and DPOAE testing needs to be evaluated, to assist in deciding which is most appropriate as a field procedure for this population working in a certain segment of industry such as the mining community (Probst et al., 1993:89). The majority of research thus far, has indicated that TEOAEs are most useful for screening purposes whereas DPOAEs are best for monitoring changes in the cochlea over time rather than as a screening tool (Probst & Harris, 1993:858; Plinkert, Hemmert, Wagner, Just & Zenner, 1999:367). Nevertheless, Hall (2002) indicates that both types of OAEs should be used to draw reliable conclusions. The feasibility of OAEs as an objective field procedure for persons exposed to noise, requires further investigation (Hall, Baer, Chase & Schwaber, 1994:22; Hotz, Probst, Harris & Hauser, 1993:482: Gorga, Neely, Bergman, Beauchaine, Kaminski, Peters & Jesteadt, 1993:2639).

1.2 Definition of Terms

Audiogram: a chart or graph depicting hearing levels as a function of frequency and intensity (SANS, 2004:7).

Distortion product otoacoustic emissions (DPOAE's): otoacoustic emissions which are evoked using the concurrent presentation of two pure tones closely spaced in frequency. DPOAEs are absent in hearing loss greater than 55 dB (Hall, 2000:16)

Hearing loss: a change for the worse in auditory structure or functioning outside the range of normal hearing (Katz, 1994:476)

Hearing screening: periodic testing for and detection of hearing impairment in order to assess for permanent threshold shifts, for the purposes of hearing conservation (SANS, 2004:11).

Noise-induced Hearing Loss (NIHL): permanent damage, caused by noise, to the outer hair cells of the cochlea resulting in a decrease of the amplification ability of the cochlea (Reshef et al., 1993:387).

Otoacoustic Emissions (OAEs): OAEs are sounds measured in the external ear canal, but are generated by and reflect vital biomechanical activity within the normal cochlea (Katz, 1994:448).

Sensitivity: Correctly identifying a significant hearing impairment and the correct identification of normal subjects (Katz, 1994:478; Hatzopoulos, Mazzoli & Martini, 1995:250).

Specificity: correctly passing a normal hearing subject and the correct identification of hearing impaired subjects (Katz, 1994:478; Hatzopoulos et al., 1995:250)

Transient evoked Otoacoustic emissions (TEOAE's): evoked otoacoustic emissions using a click or tone burst stimulus activating the basilar membrane across a wide frequency range (Hall, 2000:17).

1.3 Chapter Layout

Chapter 1:

Chapter one introduces and summarizes the research project and thus aims to provide the reader with an introduction to this field of research in industry. The areas of noise-induced hearing loss; otoacoustic emissions and the effect of noise on hearing are covered. Research in this field of OAEs and NIHL is important due to the auditory and non-auditory effects of NIHL on the individual working in high levels of noise as well as the effects on the mining industry. The chapter aims to address the question of whether it is feasible to include DPOAEs or TEOAEs successfully, within a hearing screening program for NIHL in the South African mining population. The definition of the terminology utilized in the study and the layout of the chapters is included in chapter one.

Chapter 2:

Chapter two discusses in detail the literature pertaining to noise-induced hearing loss, its effect on the worker in industry, the effects of noise, both auditory and non-auditory and the traditional methods of measuring of hearing. The chapter encompasses otoacoustic emission testing and its potential clinical use within the mining industry for the identification of noise-induced hearing loss.

Chapter 3:

The methodology used to capture the data and study the applicability of otoacoustic emission testing in the area of NIHL is described in chapter three. A cross-sectional survey design was chosen for the purposes of this study. The aim and sub-aims of the research are listed in this chapter.

Chapter 4:

Chapter four encompasses the results of the research carried out and the findings regarding the clinical use of otoacoustic emission testing for the early identification of NIHL are discussed in detail. The results are discussed in light of previous findings in the literature. The research questions are answered.

Chapter 5:

Conclusions regarding the clinical value of otoacoustic emission testing for the early identification of NIHL are made in chapter five based on the research findings and related to reports from the literature. The limitations of the project are discussed as well as further possible avenues of research.

1.4 Summary

Hence, if an initial screening technique could be implemented which is faster than the present conventional methods but reliable and sensitive to early onset of NIHL, the control of noise and its effects in industry can be improved and the degree of damage to hearing can thus be limited.

Chapter 2: Noise-induced hearing loss and otoacoustic emissions

In chapter two the auditory and non-auditory effects of hearing loss, hearing conservation programs, otoacoustic emissions and noise-induced hearing loss in the mining industry are discussed.

2.1. Introduction

Noise is a common occupational hazard, which leads to permanent sensori-neural hearing loss (Rosen et al., 2001:1). It is unique in that by the time the hearing impairment is perceived, the damage is already at an advanced stage. NIHL is common as Rosen et al., (2001:1) estimated that one third of the 30 million American adults with hearing loss have an impairment caused by noise. Hearing impairment from noise is therefore on the increase not only due to an increase in industrial noise but also due to exposure to environmental and recreational noise (Katz, 1994:611). Fifteen million Americans are said to be exposed to environmental noise levels of 75 dB(A) or more every day (Office of Noise Abatement and Control, 1981). Sources of this noise include traffic and aircraft noise, rail and industrial noise. This makes NIHL the most common preventable cause of permanent sensori-neural hearing loss. In South Africa, within the mining industry, 68 percent to 80 percent of the 350 000 mineworkers employed are exposed to significantly high levels of noise in their work environments (Guild et al., 2001:195). With the financial strain of compensation on the industry for NIHL as well as the health hazard that it poses for the mineworker, the control and prevention of NIHL has increasingly been highlighted and addressed in the past few years (Guild et al., 2001:195). Legislation has therefore been put into place and hearing conservation programs have become compulsory with a view to early detection and management of NIHL. However the proportion of compensation claims for hearing loss has escalated and has not been reduced as expected. In America it has been found that poor management of hearing conservation programs has led to an increase in NIHL and therefore in compensation claims (Daniell, Swan, McDaniel, Stebbins, Seixas & Morgan, 2002:1). Where a hearing conservation program is run effectively, a more sensitive test procedure may be the answer if it is able to detect NIHL earlier than the current methods being employed. One such method, which may prove to be useful, is that of otoacoustic emission testing (Hall, 2000:482). Over the past number of years it has been demonstrated that OAEs are useful in the differential diagnosis of sensorineural hearing loss, difficult-to-test clients and in the monitoring of outer hair cell function in clients exposed to ototoxic drugs, noise or progressive hearing difficulties (Lonsbury-Martin, Martin & Telischi, 1994:167). OAEs have most effectively been used in screening for significant hearing disorders in the neonatal population since the late 1980's. This has been successful partly due to the test's high reliability, ease and speed of performing the test (Hall, 2000:27). Only recently have researchers been examining their use in other population groups.

OAEs are highly sensitive to cochlear dysfunction, which is caused by noise exposure. There is mounting evidence that noise-induced cochlear damage is detectable with OAEs before it is evidenced on the audiogram (Hall, 2000:482; Fabiani, 1993:133). OAE amplitude is evidently lower in persons exposed to noise than non-exposed persons with similar pure tone hearing thresholds (Kowalska & Sulkowski, 1997:457). OAEs may likewise be used in monitoring deterioration in hearing in at risk populations as well as being able to detect temporary threshold shifts due to noise exposure (Fabiani, 1993:133).

The implications of this are far-reaching, as earlier management and possible prevention of NIHL and subsequent reduction of financial costs in compensation for industry as well as in the effect of hearing loss on the employee may all become attainable.

This chapter will give an overview of the effects of noise, both auditory and non-auditory, legislation and hearing conservation programs, conventional hearing testing methods, and OAEs. The possible role that OAE testing may play in hearing conservation programs as a screening tool for NIHL will be addressed. Before investigating OAEs, it is necessary to consider the characteristics of noise and its effect on hearing.

2.2. Auditory effect of noise

Noise is referred to as an intense sound capable of producing damage to the inner ear (Rosen et al., 2001:1). A possible definition of NIHL is "permanent damage to the outer hair cells (OHC) of the cochlea resulting in a reduction of the amplification ability of the cochlea" (Reshef et al., 1993:388). The nature and degree of cochlear damage resulting from noise is dependant on a variety of both intrinsic and extrinsic factors. The intrinsic factors include the individual's susceptibility to noise damage and therefore physiological changes. The extrinsic factors include the nature of the noise, the level and duration of exposure and factors such as environmental influences.

Physiologically the tissue of the cochlea is destroyed due to the physical force of the sound pressure reaching the ear. A diminished blood supply to the ear occurs and the organ of Corti becomes detached from the basilar membrane, deteriorates and is replaced by scar tissue. In addition, the biochemical processes of the cochlea are altered during noise exposure (Office of Noise Abatement and Control, 1981; Clark & Bohne, 1999:1). These biochemical changes have led researchers to begin investigating a molecular basis of NIHL and thus it is hypothesized that enzyme therapy may be used as a preventative measure (Hsu, Chen, Shau, Yeb, Lee & Lin-Shiau, 2002:842; Kopke, Coleman, Liu, Campbell & Riffenburgh, 2002:1515). As the intensity and period of exposure of the noise increases, the more cochlear hair cells are destroyed. These hair cells do not regenerate. After a number of years the hearing loss can be detected audiometrically and occurs initially in the high frequency range (Clark & Bohne, 1999:2). Sound levels exceeding 75 dB(A) to 85 dB(A) begin to stress the auditory system (Kvaerner et al., 1995:137). Noise levels in mines are at these levels, if not above (Guild et al., 2001:196). The degree of hearing impairment caused by these levels of exposure varies and can be associated with the degree of susceptibility to noise damage. Prevention of damage in more susceptible individuals thus becomes critically important as there is no cure other than prevention (Hotz et al., 1993:478).

It has subsequently been proposed that an individual's susceptibility and predisposition to NIHL is determined by anatomical differences and differences in the inherent resonance of the ear canal determine. Although this has not been fully investigated, evidence exists to indicate that persons undergoing physiological changes such as illness or physical stress become especially susceptible to suffering noise damage (Office of Noise Abatement and Control, 1981). Hong and Kim (2001:7) indicated that personal risk factors increase a person's susceptibility to NIHL. These included recreational noise exposure, history of ear disease, ototoxic drug usage, smoking, heart disease and use of hearing protection devices. This individual susceptibility, propounded by such multiple causative factors, results in difficulty to predict the degree of temporary or permanent damage which could occur (Henderson, Subramaniam & Boettcher, 1993, cited in Kaervner et al., 1995:137). The magnitude and nature of the hearing loss is also dependant on extrinsic factors: the nature of the noise, intensity levels, the duration of exposure and the spectral content of the noise (Eddins et al., 1999:119; Attias & Bresloff, 1996:230; Office of Noise Abatement and Control, 1981). Noise is characterized by its intensity and temporal patterns i.e. intermittent or continuous. Impulse or intermittent noise is characterized by short duration, sudden onset and high intensity (90 dB(A) to 140 dB(A). The main sources of impulse noise include explosions, gunfire and sudden impacts (Office of Noise Abatement and Control, 1981). Both temporary and permanent threshold shifts can occur as a result of impulse noise. Continuous noise is characterized by a longer duration at usually lower intensity levels (a daily average of 90 dB(A) (Hodge & Price, 1978:4; Clark & Bohne, 1999:2). Exposure to continuous noise for long periods of time results in hearing loss and is more damaging than exposure to intermittent noise (Rosen et al., 2001:1). High level, short duration noise exposures result in a metabolic change rather than a mechanical change in the cochlea (Clark & Bohne, 1999:2). A mechanical change occurs over a number years with continuous noise exposure. If both intermittent or impulse noise and continuous noise are coupled with body vibrations the hearing loss which occurs is exacerbated. Body vibration is the result of vibrations emitted by the machinery or tools used by the worker (Guild et al., 2001:211). These forms of noise, after sufficient exposure, cause a hearing loss which may result in a characteristic notch between three to six KHz on the audiological evaluation. Sloping or flat audiograms are also common (Rosen et al., 2001:3). This notch can be observed during the first three years of exposure (Kowalska & Sulkowski, 1997:455). The area of hearing most affected by noise is usually found to be one and a half octaves above the noise (Henderson & Hamernick, 1995, cited in Rosen et al., 2001:4). The ear converts industrial noise to the fundamental frequency of three KHz and therefore the characteristic four KHz notch is obtained. The first symptom of NIHL is difficulty hearing conversation in a noisy environment. The nature of NIHL leads to the initial loss of consonant discrimination. Especially the ability to hear high frequency consonants such as /f/, /s/, /sh/, /t/, /d/, is affected. These consonants are important to the intelligibility of speech and thus the hearing impaired person will complain of being unable to make out or understand what the speaker is saying. Conversation is significantly interfered with when hearing loss occurs above three KHz (www.agius.com: 2004). In addition, NIHL can possibly deprive the worker of occupational goals; result in an unwanted change in their job description or even a change of career (Katz, 1994: 611).

Maximum hearing losses are said to occur after 10 to15 years of chronic / continuous exposure to noise levels above 75 dB(A). Permanent hearing loss may begin after one to two years of exposure to noise or even earlier (Bohne & Clark, 1982, cited in Probst et al., 1991: 2048).

There are two phases to the progression of noise damage. Initially a temporary threshold shift, that is a short term effect of noise exposure, is experienced, which remediates. Noise exposure that is capable of producing temporary threshold shifts is likely to produce a permanent threshold shift in the long term. This permanent threshold shift is sensori-neural in nature and occurs initially in the high frequencies. This permanent threshold shift will persist throughout the life of the person, and results in irreversible changes within the sensory structures of the cochlea (Katz, 1994:611). The high frequencies are more susceptible to damage due to their proximity to the cochlea base and there are a smaller number of hair cells corresponding to the high frequencies as compared to those for the lower frequencies (Attias, Furst, Furman, Reshef, Horowitz & Bresloff, 1995:612).

Therefore the hearing loss resulting from noise damage is dependant on a number of both extrinsic and intrinsic factors. However the damage that noise causes not only affects the individual's hearing but has an impact on other aspects of his or her life as well.

2.3. Non-auditory effects of noise

Although life itself is not threatened by noise exposure, the quality of life is affected. The non-auditory effects of noise which are to be discussed can have a detrimental affect on a person's life. Excessive noise disturbs sleep, impairs communication and causes stress and with sufficient exposure causes NIHL (Clark & Bohne, 1999:1). Occupational hearing loss may negatively impact on interpersonal relationships and job performance (Katz, 1994:611). Noise levels in the environment have increased since the industrial revolution. Noise sources today include air and road traffic, personal stereo systems, guns and machinery (Office of Noise Abatement and Control, 1981; Clark & Bohne, 1999:1). Sociocusis is the term used for hearing loss caused by environmental noise (Office of Noise Abatement and Control, 1981). Most people are exposed to damaging noise within their work and recreational environments. This includes loud music from concerts or stereo systems, and traffic noise. Most people are exposed daily to noise and are affected by it either in terms of an increase in stress levels or simply an increase in annoyance. These effects are subjective in nature and largely dependant on the person affected. If noise is considered to be a cause of stress and other undesirable consequences, criteria are required. Criteria do not exist as yet for the non-auditory effects of noise.

2.3.1 Physiological effects of noise

The non-auditory effects of noise can be divided into two main areas being physiological and psychological effects of noise exposure. Exposure to high levels of noise produces temporary non-auditory physiological effects. Although there is little research in this area, it is possible that constant exposure to noise can contribute to deterioration in health (Office of Noise Abatement and Control, 1981). Noise has been reported to produce sensations of vibration, increased perspiration and heart beat, changes in breathing and muscular contractions (Newby & Popelka, 1985:331). When these reactions become frequent, harmful effects to a person's state of health and increased stress levels can occur. Simultaneous exposure to noise and vibration may have an amplifying effect on the physiological outcomes experienced. The magnitude of this effect is not fully investigated (Office of Noise Abatement and Control, 1981; Guild et al., 2001:211). However, in the light of significant vibration accompanying noise in the mines, the effects of vibration need to be considered. This is due to the fact that vibration coupled with noise can exacerbate the hearing loss caused. In the mining sector vibration induced disease is well documented. It involves either whole body vibration caused by delivery vehicles, trucks, hydraulic shovels, underground locomotives and loaders, or hand arm vibration resulting from the use of jackhammers, rock drills and rock breakers (Guild et al., 2001:214). The symptoms of vibration induced disease, in particular whole body vibration, include lower back pain accompanied by dizziness and gastrointestinal tract disorders. Symptoms of hand arm vibration include damage to the vascular and neurological systems and muscular damage (Guild et al., 2001:215). Animal studies have shown that an increase in hair cell loss and hearing loss occurs when the animals are exposed to both vibration and noise simultaneously as compared to exposure to noise alone. However in humans, vibration causes a larger temporary threshold shift after noise exposure. A permanent threshold shift has not been found to occur as is the case with the animal studies (Rosen et al., 2001:6). Vibration has been shown to induce other physiological effects similar to those caused by excessive noise. These effects include biological, psychological and social stressors.

Although opposing opinions exist to noise being a general biological stressor which state that too many variables exist in order to be able to isolate the cause of these reactions to noise alone, studies have particularly investigated the effect of noise on the cardiovascular system. Hypertension and heart disease are known leading causes of death in South Africa (Weiten, 1992:484; http://www.heartfoundation.co.za:2004). A number of studies have shown that long term exposure to noise can be associated with changes in blood pressure, cholesterol and cortisol, a stress hormone (Office of Noise Abatement and Control, 1981). Existing cardiovascular disease is exacerbated by noise exposure and vibration. This can obviously shorten the time period of productivity of the person and reduce his or her quality of life.

2.3.2 Psychological effects of noise

Not only does noise impact negatively on the physical wellbeing of the individual, but there are psychological repercussions as well. The first psychological symptom caused by noise is stress. This is manifested in a variety of ways, including headaches, insomnia, digestive disorders, fatigue, annoyance and anger (Office of Noise Abatement and Control, 1981; Weiten, 1992:473). In the presence of noise, fatigue and stress are intensified. Studies have shown that work performance and efficiency are influenced in that the accuracy of task performance and quantity of work completed decrease (Office of Noise Abatement and Control, 1981; Weiten, 1992:473). Noise interrupts a person's attention processes and reaction times and therefore the accuracy and quantity of the work is affected and the number of errors increases. These effects are more pronounced for complex tasks than for simpler tasks and are more evident in the presence of random, unpredictable noise sources (Office of Noise Abatement and Control, 1981). Random bursts of noise and high frequency noise are more disruptive to a person's performance than steady, low frequency noises (Newby & Popelka, 1985:334). Continuous noise levels above 90 dB(A) and intermittent noise, less than 90 dB(A) with a high frequency component are most likely to affect work performance, with industrial type noise having the most pronounced effect (Office of Noise Abatement and Control, 1981). Additional outcomes include exhaustion, mental strain, absenteeism and tenseness. Being unable to perform well at work affects the wellbeing of the person, their self esteem and motivation and creates an aversion to returning to work each day (Weiten, 1992:480; Kryter, 1971:481). The frequency and severity of accidents tend to be higher in noisy working environments, as warning signals are masked and errors in the task performance occur (Industrial Noise and Worker Medical, Attendance and Accident Records, 1972, cited in Office of Noise Abatement and Control, 1981; Kahneman, 1973:111).

An additional psychological factor is that of the social isolation which a hearing loss causes. Most of the literature emphasizes this as being the paramount consequence of a hearing loss. Coupled with this is the inability to communicate effectively (Katz, 1994:611). Communication forms a vital part of both personal and business life (Sataloff & Michael, 1973:79; Weiten, 1992:472). The person with a hearing loss becomes frustrated at being unable to hear and communicate. They may become increasingly isolated from society due to the reluctance of wanting to participate at social events. In most cases emotional depression is the final outcome.

Thus noise exposure not only results in hearing loss but has psychological and physiological implications. Both governments and employers have attempted to address these issues in a variety of ways. This is discussed in the following section.

2.4. Hearing conservation programs and legislation

In considering the auditory and non-auditory effects of NIHL it is important for action to be taken early. The importance of preventing NIHL has been recognized by both employers and governments around the world. It is the responsibility of the employer to provide safe working conditions and practices appropriate to the particular circumstances in each work environment. This includes the prevention of noise hazards and NIHL. Legislation has been put into place to ensure the protection of the worker from noise damage, as many workers are routinely exposed to noise levels greater than the legally recognized safety limit of 85 dB(A) (Guild et al., 2001:206). Legislation has been in place as far back as 1969 with the Walsh-Healey Public Contracts Act (Rosen et al., 2001:7). This act established a maximum noise exposure of 90 dB(A) over an eight hour period. If the noise increased by five decibels, the duration of exposure needed to be decreased by half (Rosen et al., 2001:7). Following this, the Occupational Safety and Health Act of 1993 (Act 85 of 1993) and SANS (2004:14) addressed the employees in commerce and citizens with regard to the effect of noise on public health and welfare. Regulations on hearing conservation for compulsory audiometric evaluations were circulated in South Africa in 1994 (Doke, 1996:24). The South African employer is obliged to implement a mandatory code of practice and occupational hygiene monitoring when employees are subject to noise levels exceeding 85 dB(A) (Mining Health and Safety Act, Act 29 of 1996; Occupational Hygiene Regulations cited in Guild et al., 2001:203). In terms of these acts a hearing conservation program is necessary where workers are exposed to high levels of noise daily. In addition the National Institute for Occupational Safety and Health (NIOSH) (1972,1998) recommended the establishment of hearing conservation programs for workers where noise exposure is equal to or exceeds 85 dB(A).

"Hearing Conservation" means the avoidance or reduction of noise-induced hearing impairment by the control of noise through engineering methods, and the execution of hearing conservation procedures (Guild et al., 2001:195). Within the hearing conservation program, both the employer and employee have responsibilities in fulfilling certain obligations with regard to noise. Traditionally industrial hearing conservation programs have sought to preserve the hearing of workers already exposed to noise (Probst et al., 1993:85). Since then programs have additionally emphasized the importance of prevention of NIHL. Therefore a program should include risk assessment, followed by education and training of the workers, control of the noise, personal hearing protection and medical surveillance and audiometry (Clarke & Bohne, 1999:1; Guild et al., 2001:199; Katz, 1994:542; NIOSH, 1998; SANS, 2004:14). Risk assessment entails identifying and measuring the noise source by an Occupational Hygienist (Guild et al., 2001:200). This assessment determines whether a hazardous noise source exists and whether further analysis of the noise is required. Once the hazard has been located and analyzed, the employer should try to eradicate or control the noise. The most reasonable way to do this is to generate less noise with better machinery and equipment design. Nevertheless noise controlled engineering is the preferred method but is expensive and therefore not always possible

(Guild et al., 2001:200). Where the elimination or control of the noise is not feasible, minimization is acceptable according to the Mine Health and Safety Act, Act 29 of 1996 and SANS (2004:15, 24). Examples of this include ways to minimize the worker's exposure to noise. This includes decreasing the exposure time of the workers, relocating workers, or introducing personal protection in the form of hearing protection devices (HPDs). HPDs should be provided to the worker by the employer and wearing the HPDs is the responsibility of the worker (Guild et al., 2001:198). The HPDs should provide sufficient attenuation of the noise in order to protect the wearer. Various types of HPDs are available and the type chosen is dependant on the noise and environmental conditions. In the mining sector both insert earplugs and earmuffs are available. NIHL will continue to develop if the HPDs are incorrectly inserted, used inconsistently or provide inadequate reduction in the noise. In order to effectively use the HPDs, the program requires an educational component. This is the responsibility of the employer and is frequently neglected (Katz, 1994:550). According to Guild et al (2001:199) the educational component should cover the effects of noise on hearing, the purpose of the surveillance and the proper use and fitting of HPDs. The audiologist may be involved in this phase of the program however the audiometrist usually has a larger part to play. The audiologist's primary involvement is with the medical surveillance aspect of the program. Standard medical surveillance is necessary to monitor the effectiveness of the hearing protection program and the audiologist or industrial audiometrist is required to provide hearing testing services (Katz, 1994:551). Pure tone audiometry is the conventional measurement used and is currently the only way to establish an individual's susceptibility to noise damage within the hearing conservation program (Melnick, 1994:539). The audiogram obtained reveals hearing thresholds which should be valid and reliable if the audiometer is accurately and regularly calibrated (Katz, 1994:546). The accuracy of the results is furthermore reliant on the test environment and the skill of the tester. Subsequently, if these are poor, employees in the industrial sector will and do continue to develop NIHL even though annual hearing tests are implemented. In addition doubt as to whether pure tone audiometry is the best measure to use in hearing conservation programs, given the possibility that cochlear damage might be present before changes are seen on the audiogram, has been raised (Gorga, Neely, Ohlrich, Hoover, Redner, & Peters, 1997:443). Studies have thus emerged with regard to the role of Otoacoustic emission testing in noise-induced hearing loss (Hall, 2000:484; Durrant, 1992:42). The comparison of OAE results with the results of pure tone testing has revealed a possible greater sensitivity on the part of OAEs for early detection of cochlear damage (Probst et al., 1993:80). More recently OAEs have been implemented as part of the screening test battery for early identification of NIHL in hearing conservation programs in industry. The Health and Safety Executive are considering one such screening program in the United Kingdom (http:// www. fmb.org.uk /publications / govt news: 2000).

Screening, whether with OAEs or conventional methods, forms part of the medical surveillance of the hearing conservation program. Should the screening indicate a possible hearing loss, further diagnostic testing is specified. Screening is not the same as diagnostic testing and should rather be viewed as a selection procedure for diagnostic testing (Giebel & Redemann, 1992:25). Screening tests take place in less than ideal situations. If OAEs are to be clinically useful, they should be sufficiently robust to be recorded under less than ideal circumstances (Prieve, Gorga, Schmidt, Neely, Peters, Schultes & Jestead, 1993:3318).

2.4.1 Requirements for screening procedures

To justify screening, several requirements need to be met. The first being that the impairment under investigation leads to decreased functioning and poorer quality of life. In terms of hearing loss, this is well documented. In addition for screening to be of value it should be able to detect hearing loss earlier than without the screening program implemented, and follow-up procedures, further testing and rehabilitation, should be available (Giebel & Redemann, 1992:26). A further consideration is whether the implementation of a screening technique will reduce the overall cost of identification and treatment by resulting in less persons being referred for diagnostic testing as compared to the effectiveness of the current methods in use. These requirements for screening are still under investigation.

A good screening technique needs to be simple, easy to administer and quick as well as sensitive and specific (Giebel & Redemann, 1992:25). The validity of any screening technique is influenced by these last two components. Sensitivity is determined by "the percentage of correct positives identified in the impaired population" i.e. correctly identifying significant hearing loss (Giebel & Redemann, 1992:25; Katz, 1994:612). Specificity is determined by "the percentage of correct negatives identified in the healthy population" i.e. correctly passing a normal hearing subject (Giebel & Redemann, 1992:25; Katz, 1994:612). Low specificity in screening results in a large number of referrals of persons with no disorder. Screening is not effective if the sensitivity and specificity fall well below 100 percent (Hall, 2000:409). However these values need to be evaluated for each individual screening program in order to assess the program's effectiveness. The sensitivity and specificity are affected by the population being tested, the number of subjects, the stimulus parameters and the criteria for a pass/fail result. These assessment procedures used vary between programs.

Should the screening and hearing conservation program fail to be sufficiently sensitive or specific to NIHL, the disorder will go undetected. The person's hearing will deteriorate and this may result in the employee qualifying for compensation. This is according to the Compensation for Occupational Injuries and Diseases Act (Act 130 of 1993, cited in Guild et al., 2001:388). The hearing threshold for compensation of NIHL changed in 1995 and has resulted in an increase in the number and costs of claims laid. However in 2001 a new procedure for identifying and evaluating NIHL for compensation was introduced. It is still to be assessed whether this new technique will aid in decreasing costs for the mining industry (Compensation Commissioner, Instruction 171, RSA 2001, cited in Guild et al., 2001:410). The battery of tests used at present for identifying and evaluating NIHL includes diagnostic audiometry, both pure tone and speech testing, immittance measures including reflexes, otoacoustic emission testing and any other audiometric testing necessary such as auditory brainstem response testing (SANS, 2004: 33, 34). The results of the battery of hearing testing completed, dictates whether the employee receives compensation or not. This is calculated in terms of permanent disability by using "percentage loss of hearing" and determined by the final diagnostic audiometric test results as laid out by SANS (2004, Annex E:48). It is therefore important to consider in more detail the measurement of hearing.

2.5. The measurement of hearing

Hearing is generally measured using a pure tone audiometer. Various pure tones of different frequencies and intensities are presented to the subject's ears though headphones. This is called air conduction testing (Katz, 1994:611; Office of Noise Abatement and Control, 1981). Each ear is tested separately and frequencies from 250 Hz to 8000 Hz are used. The hearing threshold for the test ear is determined at each frequency and is plotted on an audiogram. From the audiogram the hearing loss can be described in terms of its degree, shape and the type of hearing loss. The type, that is conductive versus sensori-neural, can additionally be determined if bone conduction testing is completed. Normal hearing for the adult population is defined as hearing thresholds for all the frequencies tested, to be between zero and 25 dBHL (Davis & Silverman, 1996:96). There appears to be no differences in hearing levels due to race. Any demographic differences may be attributable to varying environmental noise exposure. Hearing ability deteriorates with age. This phenomenon is called presbycusis and is most marked in the higher frequencies. It has been hypothesized that a presbycutic hearing loss may be due to or aggravated by environmental noise exposure especially in industrially developed countries rather than solely caused by ageing processes.

In the hearing conservation program a baseline audiogram is obtained from the employee at least thirty days after the commencement of the work in a noise zone or just before commencement of work in the noise zone (Occupational Health and Safety Act, 2001:8; SANS, 2004:28). Two baseline audiograms obtained within twenty minutes of each other are obtained and compared. Should these audiograms not correlate the worker is referred to the audiologist for further in depth assessment. The baseline audiogram serves as a reference for subsequent audiograms in monitoring changes in hearing status. In successive annual hearing screenings a shift of ten percent or more in percentage loss of hearing is viewed as being significant and necessitates intervention. This percentage loss of hearing is calculated by combining hearing threshold levels at 500;1000;2000;3000;4000 Hz with the use of tables from the Compensation Commissioner and those laid out by SANS (2004: Annex E:48; Guild et al., 2001:208). Claims are then submitted to the Compensation Commissioner within fourteen working days and are dealt with under the Compensation for Occupational Injuries and Diseases Act, 1993 (COIDA) (cited in Guild et al., 2001:208). There are disadvantages to using pure tone testing to measure hearing. With the measurement of the hearing thresholds, variability exists which can be associated with the state of the subject e.g. inattention, differences in testing equipment and the methodology used. Prior experience with the test procedures, attention, motivation and drug use can influence the subject's performance (Atherley & Johnston, 1981:1). The more test variability, the larger the inter-test differences. It is also difficult to detect functional hearing loss with audiometric testing. This factor becomes important where compensation is being considered. In the hearing conservation program audiometric testing serves only to document the hearing loss and determine the effectiveness of the hearing conservation program, but not to prevent it (Atherley & Johnston, 1981:1). Atherley and Johnston (1981:1) state that audiometric testing may be too variable to be useful in identifying early onset of hearing loss. Moreover it is difficult to distinguish between NIHL and other cochlear diseases using pure tone audiometry (Sliwinska-Kowalska & Kotylo, 1997:613). This has led researchers to consider other alternative methods for this purpose. One such method has been otoacoustic emission testing which has previously been mentioned.

2.6. Otoacoustic emissions

OAEs are sounds measured in the external ear canal and are generated by and reflect vital biomechanical activity within the normal cochlea (Katz, 1994:448; Lonsbury-Martin, Martin & Whitehead, 1997:964). The discovery of OAEs by Kemp (1978) has resulted in a rapidly expanding field of research due to the beneficial features of OAEs offering an easier and more effective way of assessing the cochlea. Animal studies and studies investigating the effects of ototoxic drugs or noise on various emission types have provided the evidence of the cochlea origin of OAEs (Brownell, 1990:83; Probst et al., 1991:2034). It has been hypothesized that the outer hair cells (OHCs) of the cochlea appear to be responsible for the production of OAE's within the cochlea itself. Anatomically this has been observed with the OHCs becoming fused or disappearing after noise exposure or other cochlear trauma and a subsequent decrease or disappearance of the OAE's (Attias & Bresloff, 1996:223, Bohne & Clark, 1982, cited in Probst et al., 1991:2030). The unique quality of motility of the outer hair cells is said to produce the OAE's (Kemp, 1982:189; Kowalska & Sulkowski, 1997:442 Marshall & Heller, 1998:1319). The motion of the outer hair cells in response to a stimulus produces mechanical energy within the cochlea. This energy is passed back along the pathway to the external auditory meatus where the OAEs are measured. When the sensitivity and fine tuning of the cochlea is compromised in a certain frequency range, the same range of the OAE spectrum is expected to be altered (Avan, Elbez & Bonfils, 1997:2771). Once permanent damage has occurred, the cochlea cannot recover. The cochlear damage typically progresses from basal to apical in direction and therefore the typical high frequency hearing loss associated with noise-induced hearing loss is observed (Arnold et al., 1999:215). The outer hair cells of the cochlea appear to be particularly vulnerable to trauma such as noise (Lonsbury-Martin et al., 1991:965). This has implications for the use of OAEs in detecting NIHL.

The cochlea generates different categories or types of OAEs. The ones used predominantly by clinicians and researchers are transient evoked OAEs (TEOAEs) and distortion product OAEs (DPOAEs). This is owing to their incidence (96 percent prevalence for DPOAEs and 98 percent prevalence for TEOAEs in normal ears), the ease with which measurement can be done, the excellent test-retest measures and the information obtained from each (Lonsbury-Martin et al., 1991:973). OAEs have been successfully applied in hearing screening programs in neonates however they are still under evaluation regarding their clinical usefulness and assessment of the hearing of adults (Silwinska-Kowalska, 1998:30). The sensitivity and specificity of the test utilized in any hearing screening program is of paramount importance. The sensitivity and specificity of OAEs have varied among researchers due to various pass/fail criteria and stimulus parameters being used (Nozza & Sabo, 1992:29; Giebel & Redemann, 1992:26). Reshef et al., (1993:387) assessed the clinical efficacy of screening for NIHL with DPOAEs. They reported a sensitivity of 93 percent and 92 percent specificity whereas Lucertini, Bergamaschi and Urbani (1996:79) reported a specificity of 93 percent and an 83 percent sensitivity with TEOAEs. It has, however, been generally accepted by both researchers and academics alike that OAE testing results in an acceptably high sensitivity and specificity for the identification of cochlear damage in the inner ear (Hall, 2000:356; Engdahl, Woxen, Arneson & Mair, 1996:71).

In order to measure OAEs, certain prerequisites exist. To accurately measure OAEs, an intact middle ear system is necessary (Lonsbury-Martin et al., 1991:971). The middle ear plays a role in the forward and backward transmission of the stimuli (Yeo, Park, Park & Suh, 2002:1). Deviations in middle ear pressure can affect the amplitude and frequency attributes of the OAE or in the presence of deviant middle ear pressure, the OAE will not be measurable. OAE levels may be reduced by three to six dB when ear canal pressure varies from –200 daPa to +200 daPa (Vedantam &

Musiek, 1991:440). OAE's are modified by negative middle ear pressure in the region of the mid to low frequencies (Lonsbury-Martin et al., 1992:176). Other middle ear pathologies such as otosclerosis, perforations of the tympanic membrane and middle ear effusion, can affect the measurement of the OAE response (Lonsbury-Martin et al., 1992:49). Therefore immittance measures need to be combined with OAE measurements in order to distinguish between the effects of middle ear pathology and cochlear abnormalities (Engdahl, Arnesen & Mair, 1994:103; Lonsbury-Martin et al., 1992:177).

In addition OAE measurement is also influenced by the probe fit (Baer & Hall, 1992:17). Outside of laboratory conditions, that is within a sound proof booth or a noise controlled environment, it is difficult to achieve an optimal probe fit (Kemp, Ryan & Bray, 1990: 97). This is due to the wide variety of external meatus configurations. However fitting criteria are vital such as a firm closure around the probe being necessary for an optimal stimulus to be presented. The ambient environmental noise which can contaminate the recordings is thus sealed off. The probe fit can be evaluated before testing commences by examining the stimulus waveform and the power spectrum obtained from the equipment. The waveform needs to be relatively free of oscillation and the power spectrum level across one to five KHz should be stable (Kemp et al., 1990:98). The probe microphone can be used to monitor the waveform and level of the stimulus during testing in order to ensure a consistent probe fit within the ear canal (Probst et al., 1991:2030). A wrong insertion angle can result in the probe pressing against the meatal wall, causing an internal probe blockage. This creates unwanted noise. Prieve et al., (1993:3308) also showed that OAEs are highly reliable and stable within a test session with or without probe replacement by experienced audiologists. A good probe fit as well as choosing an appropriate test environment, such as a quiet room, can reduce the ambient noise. The client's internal noise is also a factor in the OAE recording. Any movement, or internal noises such as coughing, can create difficulties in the recording of the OAE response (Baer & Hall, 1992:20). It is therefore important to eliminate environmental noise as far as possible and to request the subject to remain still during the testing.

Not only are OAE recordings influenced by external and internal noise but the age of the subject has an additional influence on the results. The amplitude of the OAE is larger in neonates and children than the amplitudes observed in adults. This can be attributed to obvious differences in the size and structure of the external meatus (Probst et al., 1991:2043). The external meatus is smaller and more cartilaginous in infants than in adults, thus changing the resonant properties of the response. Less energy is seen in the higher frequency range on the OAE frequency spectrum, in adults, with more energy seen in the lower OAE frequency range (Baer & Hall, 1992:22). This is consistent with the normal aging effect on hearing where high frequency sensori-neural hearing loss is prevalent in the older population (Lonsbury-Martin, et al., 1992:49; Collet, Gartner, Moulin, Kauffmann, Disant & Morgan, 1989:1060). The prevalence of TEOAEs tends to decrease to 35 percent over the age of 60 years (Bonfils, Bertrand & Uziel, 1988:27). DPOAEs have also been observed to decrease with age, however researchers have concluded that other factors such as peripheral auditory dysfunction may play a more prominent role (Hall, 2000:173). The influence of presbycusis and other age related effects on OAE measurements is important, if the test is to be used to accurately evaluate cochlear hearing loss especially with regard to NIHL (Oeken, Lenk & Bootz, 2000:396). However, the influence of the duration of noise exposure, more so than the effect of age, has been found to play a role in the degree of decline of the OAE amplitude (Kowalska &

Sulkowski, 1997:456). The effect of cochlear use and exposure to noise throughout life is a factor and may contribute to the variation of OAE levels across normal populations, which remains a critical issue to clinical application (Baer & Hall, 1992:22; Vedantam & Musiek, 1991:441). It is widely acknowledged that OAEs are present in approximately 100 percent of normal ears (96 percent for DPOAEs and 98 percent for TEOAEs), however some researchers have found otherwise (Hall, 2000:204). Ferguson, Smith, Davis and Lutman (2000:125) showed that four percent of otologically normal ears did not have a recordable OAE response. They attributed this to social noise exposure and commented that the two KHz region of the tracing was most affected by the exposure to social noise. Similar findings were reported by Plinkert et al., (1999:367) having found stable emissions in all but five percent of the normal adult subjects they tested. In the neonatal population however, it has been shown that OAEs are present in 100 percent of newborn ears (Tognola, Grandon, Avan, Ravazzani & Bonfils, 1999:243). These ears have obviously not had any social noise damage. Therefore due to this high incidence, OAEs have been used successfully in newborn hearing screening programs. Early identification of hearing loss in the newborn population has led to early intervention and subsequent better rehabilitation. Within the adult population OAEs have been used to differentiate between cochlear and retro cochlear damage and have helped to clarify auditory brainstem test results. Since the late 1990's research has focused on evaluating which hearing test method is best able to predict early cochlear damage, conventional audiometric testing or OAE testing. These evaluations have considered the noise exposed population and the monitoring of ototoxic drug administration (Plinkert, Hemmert & Zenner, 1995:89; Hall & Lutman, 1999:277; Engdahl & Tambs, 2002:78; Ohlms, Harris, Franklin & Lonsbury-Martin, 1990:30). Thus early intervention and improved rehabilitation is also the aim within the adult population in the area of NIHL. In addition, OAE testing is further unaffected by motivation, attention and alertness on the part of the client (Marshall & Heller, 1998:1332). Furthermore it is important to investigate both types in order to select appropriate OAE tests for different objectives in testing, e.g. screening versus diagnostic purposes (Probst & Harris, 1993:858). Both Transient OAEs and Distortion Product OAEs have been utilized successfully in newborn screening programs for detecting cochlear damage. If OAEs can be used in a similar fashion for the adult population, the implications are significant with regard to NIHL management. The aim would be to identify early cochlear damage so that prevention and rehabilitation of NIHL would be more successful than what the current statistics are indicating.

Although OAE testing is growing in popularity, it is not yet ready for widespread or routine use in the adult population. Therefore the implementation of OAEs as a screening technique in populations predisposed to cochlear damage should be carefully evaluated and researched before implementation (Durrant, 1992:42). Thus discussion regarding the different types of OAEs and their application within the area of adult audiometry is useful when considering their possible implementation within adult hearing screening programs.

2.7. Transient Evoked OAEs

Transient Evoked OAEs (TEOAEs) are elicited using a click or tone burst presented to the ear. The cochlea is activated from its apex to the basal region simultaneously. TEOAEs show promise as a screening and monitoring tool of cochlear function. They are stable over time and repeatable within an individual's ears (Probst et al., 1991:2050; Engdahl et al., 1996:71) Good test-retest results have been obtained, which show that TEOAE results can be considered to be more reliable than pure tone audiometry retesting (Hall & Lutman, 1999:277). TEOAEs are known to be abolished by factors causing sensori-neural hearing loss and absent once the hearing thresholds exceed 30 dBHL (Hall, 2000:15; Kemp, 1978, cited in Probst et al., 1991:2048). Therefore OAE's are extremely sensitive to identifying even the mildest of cochlear damage.

When measuring the TEOAE response, the TEOAE obtained is composed of a multi-frequency response with a distinct amplitude, latency and duration (Probst et al., 1991: 2046). The response is plotted on a power spectrum where the amplitude of the TEOAE is estimated. The presence and analysis of a TEOAE is determined by a set of criteria. In general, researchers have used two response parameters to analyze the data i.e. waveform reproducibility (in percentage %) and echo level (in decibels dB). The waveform reproducibility percentage has been the standard and most accurate TEOAE measure used to date (Prieve et al., 1993:3308). Reproducibility is the measurement and correlation between two stimulus waveforms, A and B, collected during the same test (Hall et al., 1994:31). The reproducibility is described for the entire spectrum as well as for the individual octave bands one to four KHz. The percentage used to indicate a present TEOAE has varied from 50 to 70 percent (Hall, 2000:15; Lucetini et al., 1996:86; Lonsbury-Martin et al 1992:50; Vendantam & Musiek, 1991:435; Tognola et al., 1999:248). These differences have an effect on the sensitivity and specificity values resulting from the testing. The higher the criteria used the more specific and sensitive the test will be. Lonsbury-Martin et al., (1991: 971) suggest that an echo level of five dBs or more with a reproducibility value of 50 percent or more is indicative of a present TEOAE and therefore of hearing levels better than 25 dBHL to 30 dBHL.

Subsequently, Lonsbury-Martin et al., (1994:173) stated that to ensure that a valid test is performed the whole-wave reproducibility value should be more than 50 percent. If a screening is completed with pass/fail criteria, it is acceptable to use a reproducibility of 50 percent or more for a subset of frequency bands. The second parameter used to measure TEOAEs is the echo level, in dB. This constitutes the amplitude of the TEOAE. No normative data exists for the echo level parameter in the adult population, and therefore both parameters, reproducibility and echo level, should be used in conjunction to determine the presence of TEOAE's (Hall et al., 1994:31; Hall, 2002). The analysis of TEOAEs can be conducted in two ways. The first is a broadband approach which judges the TEOAE response as a whole. A pass/fail criterion is used to determine the possible presence of hearing loss. The second analysis is a narrow band approach where the broad band response is analyzed into separate frequency bandwidths to determine the presence of a hearing loss (Tognola et al., 1999:243). This is compared to the hearing thresholds obtained with pure tone audiometry. Although it is not possible to predict actual auditory thresholds from the narrow band analysis of the TEOAE response, it is possible to conclude whether cochlear damage is present in certain frequency bands (Tognola et al., 1999:248). This would greatly assist in determining early cochlear damage in the mining population.

The region of the strongest evoked response for TEOAEs lies within 500 to 4000 Hz, with one to two KHz being the most robust (Lonsbury-Martin et al., 1991:967; Probst et al., 1991:2044). Robinette (1992:35) showed that TEOAEs had good frequency specificity for high frequency hearing loss. The sensitivity of TEOAEs has been reported to be as high as 90 percent at two and four KHz (Hall & Lutman, 1999:277). Prieve et al., (1993:3317) confirmed that TEOAEs conclusively separate normal from abnormal ears at two and four KHz. In a study assessing the effects of noise exposure, Vinck, van Cauwenberge, Leroy and Corthals (1999:44) indicated that both reproducibility scores and amplitude measures for the four KHz band of the TEOAE response exhibited the greatest sensitivity. Though TEOAEs are able to identify cochlear damage, the test is unable to quantify the hearing loss present and therefore other methods such as pure tone testing are still required.

Variations in the incidence of TEOAEs may be explained by the differences in the number of subjects and in the technical procedures used between researchers as well as the experience of the testers. Middle ear pressure, equipment related difficulties, previous exposure to recreational noise and noise generated by test subjects can also cause variation in the results (Probst et al., 1991:2043). Some researchers have found TEOAE's to be present in all otologically normal ears (Robinette, 1992:34). In general there appears to be agreement that the incidence of OAEs in normal adult ears is high and it appears to be a reliable procedure to assess cochlear functioning.

Noise-induced hearing loss has been associated with a reduction in TEOAE amplitude (Probst et al., 1991:2048). In general temporary threshold shifts have been used to investigate this. Researchers have thus studied temporary threshold shifts and the effect on the OAE, in order to predict possible long term outcomes of hearing loss, should a permanent threshold shift take place. Research on the influence of temporary threshold shift and TEOAE's indicated that the type of noise the subjects were exposed to, had an effect on the region of amplitude change of the OAE. Significant changes were mainly found to centre on the two KHz frequency region of the OAE response (Hotz et al., 1993:478; Marshall & Heller, 1998:1330). Temporary threshold shifts usually develop into a permanent threshold shift. With a permanent threshold shift, more so than with temporary threshold shifts, OAEs are thought to have potential as an indicator of preclinical hearing loss. That is, it may be the case for permanent threshold shift that the OAE amplitude can decrease without any observable change in the audiometric thresholds (Marshall & Heller, 1998:1333). Sufficient data is not yet available regarding the exact relationship between a permanent threshold shift and TEOAEs (Kowalska & Sulkowski, 1997:442).

In subjects exposed to industrial noise in an everyday noisy environment, Kvaervner et al., (1995:137) found a significant reduction of overall TEOAE amplitude. From these reports, TEOAE amplitude appeared to be reduced in the region of the fundamental frequency of the noise source. In addition, Attias et al., (1995:612) found a larger reduction in TEOAE amplitude and frequency range in subjects exposed to noise with normal audiograms than those subjects with normal audiograms who had not been exposed to noise. This study thus indicated that TEOAEs are possibly more sensitive to early noise damage not yet detected by the pure tone audiogram. Kowalska and Sulkowski (1997:441) also concluded that early stages of NIHL can be identified using OAE measures when they observed a reduction of TEOAE energy and amplitude, especially at four KHz in noise-exposed subjects with normal audiometric results. Similar findings were observed by Robinette (1992:30) where TEOAEs were found to be absent within the frequency range where a notch was obtained in the audiometric thresholds. The studies discussed so far took place under laboratory conditions and the use of TEOAEs as a screening tool outside of the laboratory is limited. However similar results were obtained in both laboratory conditions and field procedures. The field studies correlated with the laboratory studies in that the range of frequencies affected by the noise exposure were similar. In field procedures, Engdahl et al., (1996:25) investigated the applicability of TEOAEs as a screening tool among military recruits. It was found that TEOAE levels decreased slightly after the noise exposure and were found to be highly repeatable with a higher sensitivity than pure tone audiometry for detecting small changes in cochlear function. An earlier study indicated similar results with 48 percent of a noise-exposed group with normal hearing thresholds had abnormal evoked emissions (Bicciolo, Ruscito, Rizzo & Frenguelli, 1993:505). In the subjects with NIHL, missing frequency bands especially in the high frequency regions was apparent. Therefore not only have TEOAEs been found to be absent in normal hearing subjects exposed to noise, they have also been found to be absent in the corresponding frequency region on the audiometric configuration in the presence of NIHL. TEOAEs have thus indicated early onset of NIHL in noise exposed subjects with normal audiometric findings. Therefore absence of emissions unaccompanied by a hearing loss could be considered to be an early indication of cochlear damage (Attias et al., 1995:618; Lucertini, Moleti & Sisto, 2002:972). It may therefore be concluded that "TEOAEs may be used as a significant tool to screen adults at risk of NIHL" (Reshef et al., 1993:394).

In the light of these findings there remain certain limitations to the use of TEOAE testing in adult populations. Such limitations include the lack of widely accepted criteria for the interpretation of TEOAE data and normative database studies (Hall et al., 1994:31). Therefore DPOAEs have been recommended as a further differential diagnostic test in evaluating NIHL (Oeken & Muller, 1995:473).

2.8. Distortion Product OAEs

DPOAE's are also used to assess normal cochlear outer hair cell function (Kimberely & Nelson, 1989:365). Distortion Products (DPs) are evoked by the simultaneous presentation of two pure tones (f1 and f2) which differ in frequency (Hall et al., 1994:22). The entire basilar membrane is not activated as with TEOAEs. Instead only the section corresponding to the frequency of the pure tones, f1 and f2, is stimulated (Hall, 2000:17). DPOAE's become absent in hearing loss greater than 55 dBHL thus being less sensitive for detecting hearing loss than TEOAE's (Oeken & Muller, 1995:473). The frequency range tested is larger than for TEOAEs and includes five to eight KHz (Hall, 2000:23).

There are two approaches in testing for DPOAEs. The first is where the intensity level is held constant with the f1 and f2 being varied. In this instance a DP gram is obtained. The second approach is to vary the intensity level and keep the frequency constant. An input/output function is thus obtained (Hall et al., 1994:31). DP grams are obtained when f1 and f2 are simultaneously presented to the ear. The lower frequency tone is referred to as the f1, its intensity level being L1. The higher frequency tone is thus the f2 with its intensity level being referred to as L2. Sutton, Lonsbury-Martin, Martin and Whitehead (1994:161) indicated that L1 equal to 65 dB and L2 equal to 55 dB may be most sensitive to detecting early changes in the cochlea due to noise exposure. The most robust and most frequently measured DP occurs at the frequency determined by 2f1-f2 (Lonsbury-Martin et al., 1994:174). In this study the use of the term DPOAE refers to the 2f1-f2 distortion product. The geometric mean of f1 and f2 assesses the actual area of the cochlea that is stimulated (Hall et al., 1994:22; Attias et al., 1998:1; Lonsbury-Martin et al., 1997:83). The geometric mean is defined as "the logarithmic mean of the two primary tones, which is computed by taking the square root of the product of the frequency" of f1 times that of f2 (Lonsbury-Martin et al., 1994:174). In this way DPOAE amplitude is measured. DPOAE amplitude is the most commonly measured feature. The amplitude of the DP varies with the parameters of the two stimulus tones, for example the largest DP amplitude is obtained when f2/f1 is equal to 1.22 and L1minus L2 is equal to ten or fifteen decibels (Gaskill & Brown, 1990:822). The frequency range for detecting reliable DPOAEs is between one and eight KHz (Probst et al., 1991:2054).

On the DP gram a distortion product (DP) is identified as an emission when its amplitude exceeds the noise floor by at least 5 dB (Baer & Hall, 1992:20). DP amplitudes as low as 3 dB more than the noise floor have been suggested to identify the DP (Lonsbury-Martin, Whitehead & Martin, 1991:971). A representative protocol would thus include a frequency range from 500 to 8000 Hz, an f2/f1 ratio of 1.22, a level difference of ten and absolute levels of L1 equal to 65 dB and L2 equal to 55 dB (Gorga et al., 1997:440).The advantage of using a DP-gram is that it describes the frequency pattern of cochlear impairment. Researchers have found that the DP-gram changes in a typical manner following continuous noise exposure. The characteristic shape of the DP gram in NIHL is displayed as a notch at three to four KHz which is not seen in other cochlear impairments. Therefore a careful analysis of the DP gram may assist in differentiating between NIHL and other impairments (Silwinska-Kowalska, 1998:43; Lonsbury-Martin et al., 1997:89). Engdahl and Kemp (1996:15) found that DPOAE amplitude in subjects exposed to noise was greatly reduced in the frequency region, three to six KHz. This being half an octave above the frequency of the noise presented. In both laboratory conditions and field procedures, using both intermittent and continuous noise, numerous researchers observed notching on the DP gram within this frequency region after subjects were exposed to noise (Eddins et al., 1999:119; Vinck et al., 1999:44; Martin et al., 1990, cited in Kim, Leonard, Smurzynski & Jung, 1992:99; Kim et al., 1992:99; Sliwinska-Kowalska & Kotylo, 1997:613; Konopka, Pietkiewicz & Zalewski, 2000:745). Gorga et al., (1993:440) also noted that by using DPOAE amplitude measures, it was possible to identify high frequency hearing loss using the frequency range of three to six KHz. These studies thus indicated that whether intermittent or continuous noise sources were used, notching appeared on the DP grams of the exposed ears. The notching was generally evident in the four to six KHz range and this confirms the frequency specific information provided by DPOAEs as opposed to the information obtained from TEOAEs.

The main advantage of DPOAEs is the high frequency specificity they provide, where specific frequencies can be selected in the measurements made (Hotaling, Blank, Park, Matz, Yost, & Raffin, 1994:3). It is within the high frequency range that NIHL first develops and according to Silwinska-Kowalska (1998:43) a definite relationship exists between NIHL and DPOAEs. The rationale for investigating this relationship has been that DPOAEs can provide frequency-specific information regarding the functioning of the outer hair cells of the cochlea (Eddins et al., 1999:120). Oeken and Muller (1995:473) went as far as to say that DPOAEs are preferable to TEOAEs in detecting NIHL, due to the characteristic of frequency specificity and the fact that DPOAEs are less affected by ambient noise than TEOAEs (Baer & Hall, 1992:20).

The frequency range affected due to NIHL, as depicted both on the DP gram and audiogram, is similar and thus DPOAEs have the best promise of predicting hearing thresholds. Kemp et al., (1990:94) suggested the existence of a relationship between the spectral analysis of the OAE and the audiogram. This relationship is still under investigation and no application to the wider population has been established (Collet, Veuillet, Chanal & Morgan, 1991:164). Though there is no general absolute relationship between hearing thresholds and the absolute levels of the OAEs, researchers have compared audiograms with the outcome of the DPOAE recording to further illustrate the frequency specificity of the DPOAE test (Engdahl et al., 1996:25). Researchers are hopeful that in future certain DP features may be correlated to particular hearing loss etiologies (Lonsbury-Martin & Martin, 1990:144; Lonsbury-Martin et al., 1992:52). Good agreement between the audiogram and the results of the DPOAE are expected in NIHL, as noise damage results in temporary or permanent behavioral threshold elevations and in decreased amplitude of the DPOAE. The most common DP feature used to correlate with hearing thresholds has been amplitude. Osterhammel and Rasmussen (1992:40) demonstrated that DPOAE amplitudes correlated with the audiogram of a noise-exposed subject where a high frequency hearing loss, above two KHz, was evident on both graphs. Thus the DPOAE amplitudes are reduced in the corresponding elevated frequency regions, three to six KHz, of the behaviorally measured hearing thresholds. This relationship has been confirmed by other researchers (Suckfull, Schneeweb, Dreher & Schorn, 1996:530; Lonsbury-Martin & Martin, 1990:145; Harris, 1990:594; Probst & Hauser, 1990:236). With regards to normal audiometric ears, Attias et al (1998:45) discovered that 25 percent of the audiometrically normal hearing ears, exposed to noise had absent DPOAEs at certain frequencies. This finding correlated with a previous study by Attias and Bresloff (1996:221) who found that temporary emission threshold shifts were unaccompanied by pure tone threshold shifts after subjects were exposed to noise. Therefore an absence of DPOAEs does not necessarily indicate hearing loss but does indicate early OHC damage. Vinck et al., (1999:44) confirmed this in a study observing the recovery of DPOAE and hearing thresholds after inducing temporary threshold shifts. The pure tone audiogram showed full recovery within a few hours whereas the DPOAEs at four KHz did not fully recover. They suggested that DPOAEs are more sensitive in detecting subtle changes in cochlear functioning than pure tone testing. Alternatively Sutton et al., (1994:172) showed that

DPOAEs were equally but not more sensitive than pure tone hearing measures in detecting the effects of acoustic overstimulation. Therefore in general, the studies have shown that DPOAE amplitude is found to decrease frequency specifically, and is sensitive to the effects of acoustic trauma.

Analyzing the audiogram as compared to the pattern of the emission response in this way can either agree or disagree. Disagreement between the two measures indicates one of three possibilities. The primary site of the pathology may be situated more proximally than the OHCs; pseudohypacusis is present and therefore no pathology is present or DPOAEs are capable of identifying cochlear dysfunction before it is behaviorally present (Lonsbury-Martin et al., 1994:177). Bohne and Clark (1978) cited in Sutton et al (1994:172) demonstrated that 30 percent of OHCs can be damaged within the cochlea before any evidence of this is seen on the audiogram. This damage is however detectable using DPOAE measures and thus supports the findings that DPOAEs may be able to detect early cochlear damage. In terms of high frequency hearing loss as is the case with NIHL, Subramaniam, Henderson and Spongr (1994:309) indicated that DPOAEs are able to detect small lesions in the OHCs but are not as sensitive at low frequencies. This was also previously established by Gorga et al., (1993:2050). Findings that DPOAEs are sensitive in this frequency region to damage, implies that the test may be used as a means of detecting and diagnosing NIHL earlier. As with TEOAEs, this reduction in DPOAE amplitude has been observed within the high frequency region corresponding to the area where initial noise damage occurs on the audiogram. However due to the frequency specificity of DPOAEs, they may be more reliable in being correlated with pure tone findings than TEOAEs. As the research has indicated, the absence of DPOAEs in the presence of normal audiometric configurations may be a sign of early cochlear damage due to noise exposure.

Although DPOAEs have rarely been investigated as a screening tool for NIHL in adult populations the findings have been similar to that of TEOAEs (Attias et al., 1998:39). Attias et al (1998:39) confirmed this in that DPOAE amplitude levels were reduced at one, three and four KHz in exposed adult ears in a hearing screening program. Although DPOAE recordings are said to be less influenced by ambient noise and therefore may be the more appropriate method to use in noisy environments, studies have shown otherwise (Baer & Hall, 1992:20). DPOAEs have been shown to be highly variable even in normal hearing subjects. This has been attributed to poor probe fit, and differences in ear canal volume and resonance (Roede, Harris, Probst & Xu, 1993:273). Slight differences in middle ear pressure can also cause variation in DPOAE amplitudes. However it was indicated that the test could be used as a valuable testing tool. The majority of researchers have concluded that DPOAEs are a useful tool in monitoring changes in the cochlea over time where screening is not the sole aim (Attias & Bresloff, 1996:221; Attias et al., 1998:39; Durrant, 1992:42; Wang, Wang, Tai, Lin & Shiao, 2002:285). It may be more useful as an auxiliary tool within a test battery for differentiating NIHL from other cochlea diseases (Wang et al., 2002:285). Although DPOAEs may be useful in monitoring changes in the cochlea over time or as a diagnostic tool, TEOAEs may be more useful in the initial screening of the clients. Further research is still required to ascertain the applicability of DPOAEs and TEOAEs within an adult hearing screening program (Attias & Bresloff, 1996:232; Attias et al., 1998:45; Hotz et al., 1993:478; Osterhammel & Rasmussen, 1992:41). Having discussed the uses of TEOAEs and

DPOAEs for the purposes of screening and identifying NIHL, their applicability to the mining industry is to be considered.

2.9. The mining industry

Large numbers of people are exposed to high noise levels within the mining industry. Between 68 to 80 percent of the employees are exposed to noise levels of 85 dB(A) or more during a work shift. A significant risk exists for these employees for developing hearing loss (Guild et al., 2001:195). NIHL entails substantial economic costs for the mining industry. In addition to this is the social handicap associated with NIHL and the fact that the quality of life is greatly reduced for the person with a hearing impairment. This underlines the importance of having effective regulatory strategies for noise control and prevention in place. The source of these high noise levels stems primarily from the mining equipment used such as drills, shovels, and crushers and other items of mining and mineral processing equipment. The equipment used is inherently noisy, and most require operator attendance (Department of Minerals and Energy Noise Control in Mines, Document number: ZMR922UU, 1997).

Both the noise and vibration produced by the equipment have a dual effect in exacerbating the noise damage. **Table 2.1** indicates the noise and vibration levels which some of the equipment produces. The sound levels are shown when hearing protection is used and when it is not. From **Table 2.1** it can be seen that in some cases, even with hearing protection being utilized, noise levels are still high.

Table 2.1: Noise and vibration levels of mining equipment (adapted from Guild et al., 2001: www.kyent.com; Department of minerals and energy, Western Australia, 1997)

Source: underground mining equipment	**Noise level at operators ear in dB(A) SPL**	**Vibrational risk rating**
Ventilation fans	90-110 (unattenuated) 90-95 (attenuated)	Low
Underground locomotives	80-95 (unattenuated) 80-85 (attenuated)	High
Chain conveyors	100-105 (unattenuated) 90-98 (attenuated)	Medium
Haulage trucks	90-100 (unattenuated) 81-90 (attenuated)	High
Pneumatic drills, airleg drills	118-120 (unattenuated) 110-115 (attenuated)	High
Source: surface mining equipment		
Rotary drills	75-100 (unattenuated) 75-90 (attenuated)	Medium
Percussion drills	105-120 (unattenuated) 80-105 (attenuated)	Medium
Dump trucks and bulldozers	85-100 (unattenuated) 78-90 (attenuated)	High

With such high noise levels present in the working conditions of the mines, both in South Africa and Australia, hearing conservation programs have been in place since 1988 (COMRO User Guide No.11, cited in Guild et al., 2001:195). These programs follow strict guidelines which both the employer and the employees should abide by when implementing the program. These include risk assessment and management, noise monitoring, education and medical surveillance as were discussed in section 2.4 (Guild et al., 2001:195; SANS, 2004:14). In the South African mines medical surveillance takes place annually with routine audiometric tests and medical examinations. These are completed before the worker is allocated to work in a noise zone (>85 dB(A)) or is performed within thirty days of commencement of employment in the noise zone. This is in order to obtain a baseline audiogram as a reference for evaluating future changes in hearing thresholds (Guild et al., 2001:204; SASCOM, 2004). The mine worker is then tested annually after the mine worker's leave or after a sixteen hour period with no exposure to noise. In this way temporary threshold shifts (TTS) do not become a consideration in the audiometric testing. For workers employed in high risk areas (>105 dB(A)), a six monthly monitoring is required (Guild et al., 2001:204; SASCOM, 2004). This assists in evaluating TTS and the efficacy of hearing protection devices. Automatic audiometers are primarily used to obtain hearing thresholds. This assists in reducing procedural differences as they are programmed to obtain thresholds using the same method as that used with a manual audiometer (Melnick, 1994:543; Guild et al., 2001:204). However, the tester does not have as much control over the testing situation as with a manual audiometer. The worker may become familiar with the test procedure over time which lends itself to inaccurate results being obtained. The worker is referred for diagnostic testing when inconsistent results are obtained in the annual test, or if ear pathology is present or the worker becomes a candidate for compensation (Guild et al., 2001:205). According to Guild et al., (2001:206), the Occupational Health and Safety Act (1993, regulation 307) and SANS (2004:27) various personnel are able to perform the hearing testing. The Occupational Health and Safety Act (1993, draft noise-induced hearing loss regulations of 2001:9) and SANS (2004:27), state that the audiograms can be performed by a "competent person" i.e. an audiometrist, audiologist or hearing aid acoustician registered with the Health Professions Council of South Africa or who have a certificate in audiometry recognized by the Department of Mines and Energy (DME). Screening audiometry is usually completed by these personnel. If diagnostic testing is required then the employee should be referred to an audiologist. The difficulties in the area of screening arise when pseudohypacusis is suspected. Pseudohypacusis refers to false or exaggerated hearing loss results (Katz, 1994:553). It is inevitable in the light of financial compensation being available for the acquisition of NIHL, that pseudohypacusis is prevalent in this population (de Koker, 2001; Katz, 1994:553). Katz (1994:553) states that the number of persons with pseudohypacusis may be increasing since the implementation of laws concerning hearing protection in the workplace. Barelli and Ruder (1970) (cited in Katz, 1994:553) found that 24 percent of workers who were applying for compensation, attested to having pseudohypacusis. It is required that these persons are referred for diagnostic testing to establish true hearing thresholds. This ultimately translates into additional costs for the employer, in this case, the mine. To address the problem of pseudohypacusis, an objective measurement is required where false measurements are not a possibility. OAE testing may aid in solving this dilemma. Sliwinska-Kowalska (1998:29) found that DPOAEs and TEOAEs were effective in detecting and aiding differential diagnosis of pseudohypacusis. With the possibility of using OAE testing as a screening technique before diagnostic testing is instigated, the number of employees being referred for diagnostic testing may be reduced. However it needs to be taken into consideration that absent or reduced OAE's can still be found in the presence of normal audiograms.

In addition the impact of HIV on cochlear dynamics is unknown. HIV is a growing concern within the South African population and new studies have tentatively concluded that there is a link between HIV/Aids and sensori-neural hearing loss. A prevalence of 23 percent of sensori-neural hearing loss among HIV/Aids adult sufferers in Gauteng, South Africa was estimated. This study did not however include OAE testing (Khoza & Ross, 2002:26). Therefore the presence of HIV in a subject or mineworker may have an effect on OAE recordings. This however requires further investigation.

Both OAE tests and audiometric tests have their limitations as do hearing conservation programs. Broad deficiencies in a sample of programs run in the United States, more particularly in Washington State, were recently documented by Daniell et al., (2002:1). The researchers investigated the hearing conservation practices of ten foundries in industry with a high rate of compensation claims. The study suggested that workers continued to face a substantial risk of developing NIHL due to poor management and implementation of hearing conservation programs. It was both poor education of the employees regarding NIHL and poor noise management on the part of the employer. These findings are possibly applicable in the South African context although no relevant research is currently available. Whatever the area of failure may be, only once both the employee and employer become part of the solution can hearing conservation programs really begin to work (Doke, 1996:26). OAE testing, for the early identification of NIHL, may be just one answer in reducing and managing the incidence of NIHL. Therefore this study aims to assess the applicability and feasibility of including OAE testing in hearing conservation programs for the early identification of NIHL. Can OAE testing be a more sensitive and specific means to identify NIHL and therefore lead to more accurate management of NIHL within the mining industry?

2.10. Summary

OAEs have a number of properties which make them ideal both for clinical and screening purposes. They are an objective measure which is ideal for examining difficult to test subjects as well as for cases of pseudohypacusis. The tests are quick and accurate and minimal patient setup time is required. The measurements are noninvasive. OAEs are able to reveal cochlear damage and evaluate the sensory functioning of a sensory-neural hearing loss. Due to their origin in the OHCs of the cochlea OAEs are highly sensitive to common forms of damage such as noise and ototoxic drugs. An additional advantage is that OAEs are present in nearly all normal ears. Lastly, OAEs are also sensitive to early onset of hearing problems. In view of these advantages, OAEs have a number of clinical applications. These include differential diagnosis of hearing loss, hearing screening, monitoring the progression of hearing loss, and identifying pseudohypacusis. The OHCs of the cochlea are in particular affected by noise damage and therefore good agreement between the pure tone audiogram and the frequency analysis of TEOAE spectrum and DP-gram is expected. Experimental work has indicated the absence or reduction of the OAE responses in the presence of NIHL. High frequency hearing loss has caused high frequency reductions in the OAE response (Lonsbury-Martin & Martin, 1990:144). Similar results have been found where no hearing loss is evident on the audiogram. This has thus shown that OAEs have the potential to indicate initial onset of noise damage before it is observed audiometrically (Lonsbury-Martin et al., 1994:178).

It is difficult to differentiate between NIHL and other diseases with a cochlear origin by means of conventional hearing tests and OAE tests. Often the damage caused by different pathologies occurs in a similar frequency region. OAE testing is a relatively new tool for assessing cochlear function in the adult population. OAEs do give an opportunity for evaluating cochlear outer hair cell function, which is most susceptible to noise damage (Sliwinska-Kowalska & Kotylo, 1997:29). Issues surrounding the nature of OAEs and noise as well as their relationship have been described in this chapter. The possible applications of OAEs in a screening program have been outlined. It appears that the majority of research is indicating that OAEs may have a role to play in hearing conservation programs (Attias & Bresloff, 1996: 221; Attias et al., 1998:39; Durrant, 1992:45; Reshef et al., 1993:387). With OAEs being able to detect early noise-induced damage before conventional audiometric testing, these tests could be used as an initial screening tool for monitoring noise exposed employees (Xu, Van Cauwenberge, Vinck & De Vel, 1998:19). However their application in programs needs to be carefully evaluated and researched before implementation, as there is an existing lack of standardized procedures and criteria for evaluation. According to Lonsbury-Martin et al., (1992:50) and Durrant (1992:45) there are still theoretical, practical and technical issues at stake. These include the need for effective test protocols to be developed, the customization of stimulus parameters for different population groups as well as the usefulness of each emission type in addressing different disease conditions. More importantly, the interpretation of OAE data differs between clinics. There is therefore a need for research within this area of OAEs and NIHL.

With the objective and rapid test administration properties of OAEs, it may be the ideal future procedure for screening large numbers of mining personnel. There are still few existing studies with regard to this (Hotz et al., 1993:478, Kvaerner et al., 1995:137). The feasibility of applying either TEOAEs or DPOAEs to a large population is yet to be determined and a clear definition of the role of OAEs in the auditory test battery is still to be fully formed. Is it therefore feasible to include DPOAEs or TEOAEs successfully, within a hearing screening program for NIHL in the South African mining population?

Chapter 3: Methodology

This chapter discusses the methodology and procedures utilized to investigate the aims of the study.

3.1. Main Aim

To determine whether otoacoustic emission testing (OAEs) can be used for the early identification of noise-induced hearing loss (NIHL) in South African mineworkers.

3.2. Sub-aims

3.2.1 To ascertain the prevalence of TEOAE's in a population of mineworkers, who are exposed to noise, with normal audiometric thresholds;

3.2.2 To determine the characteristics of TEOAE's in a population of mineworkers, who are exposed to noise, with normal audiometric thresholds;

3.2.3 To ascertain the prevalence of DPOAE's in a population of mineworkers, who are exposed to noise, with normal audiometric thresholds;

3.2.4 To determine the characteristics of DPOAE's in a population of mineworkers, who are exposed to noise, with normal audiometric thresholds;

3.2.5 To establish the prevalence of OAEs with regard to the number of years of service;

3.2.6 To describe the effect of age on the characteristics of the OAE results;

3.2.7 To ascertain inter-test and inter-tester reliability, using two OAE machines for data collection;

3.2.8 To determine the sensitivity and specificity of TEOAE's for the early detection of NIHL;

3.2.9 To determine the sensitivity and specificity of DPOAE's for the early detection of NIHL.

3.3. Research design

Descriptive studies are used to describe certain characteristics of a target population. Cross-sectional surveys fall within the category of descriptive studies (Howell, 1995:5). A cross-sectional survey design was chosen for the purposes of this study. This was in order to maximize the generalization of the findings to the identified population, to retain statistical control of the data as well as the quality of naturalness (Guy, Arafat, Edgley & Allen, 1987:55). A survey is a comprehensive examination of phenomena and is used to study the distribution of one or more phenomena or characteristics in a population (Abrahamson, 1983:67; Mason & Bramble, 1989:45). This design enables the researcher to generalize the findings from a small sample to the general population. A cross-sectional design examines behavior at one given point in time (www.faculty.ncwc.edu/toconnor, 2004). The phenomena that OAEs become absent in the presence of cochlear damage before the damage is noted on the audiogram, is to be described. The findings will possibly be generalized to the target population. Large samples are more feasible with a survey design. This design additionally permits the standardization of measurements. In surveys the statistical controls as well as the characteristic of naturalness are not completely sacrificed. Naturalness refers to no contamination of the behavior under investigation by other sources (Guy et al., 1987:56). Surveys tend to consist primarily of questionnaires or interviews, whereas with this study both objective measurements and a questionnaire were used (www.faculty.ncwc.edu/toconnor, 2004). The questionnaire was not self-administered as is generally the case but occurred in an interview situation. It was a structured interview where the answers were highly restricted. The questionnaire was used for screening the subjects and the objective measures were analyzed statistically and used primarily to describe the phenomena under investigation, and therefore the usual limitations of a survey design did not have a significant effect on the study. The limitations of a survey include relying on the respondents' memory, motivation and abilities (Guy et al., 1987:57). The variation of these can affect the results. Therefore with regards to this study a cross-sectional survey design was used for the selection of subjects and objective measures were used to obtain data for statistical analysis (Howell, 1995:4). The objective measures were used to describe variables such as inter-test reliability, the effects of age, sensitivity and specificity of the tests.

3.4. Sample

Random sampling was used to identify and select subjects from two subgroups that is, a novice, non-exposed group of mineworkers and a noise-exposed group of mineworkers.

3.4.1. Criteria for subject selection

Subjects were selected according to set criteria. Should these criteria not be met, the results of the study would be negatively impacted upon.

3.4.1.1. Normal hearing acuity

To accurately determine the sensitivity of OAEs for the early detection of cochlear damage due to noise exposure, only subjects with normal hearing ability were chosen according to the results of a pure tone audiogram completed in the routine hearing screening on the mine. The prospective subjects were those falling within the mine's classification of "Category 1" with hearing thresholds less than 25 dBHL. This criterion follows that of Clark's (1981, cited in Katz, 1994:105) where the recommendation on describing normal ranges and hearing impairment, recognizes normal hearing as being between –10 and 25 dBHL, from 250 Hz to 8000 Hz. The audiogram was repeated in a sound proof test booth by a qualified audiologist before the OAE testing took place.

3.4.1.2. Normal external and middle ear functioning

An otoscopic examination of the external meatus was performed, bilaterally, for each subject. If impacted cerumen, growths in the meatus and redness of the tympanic membrane were observed, the subjects were excluded from the study and referred for medical management. The presence of these can affect the amplitude of the emission adversely (Hall & Mueller, 1997: 252).

It is well documented that OAE transmission is adversely affected by middle ear pathologies. A deviation in the amplitude of the emission occurs if middle ear pathology is present (Hall & Mueller, 1997:252; Gorga et al., 1997:442). It is therefore important to rule out any middle ear pathologies. Only subjects with Type A tympanograms were included in the study. A Type A tympanogram is best described by a middle ear pressure of –100 to +100daPa, ear canal volumes of 0,65ml to 1,75ml and a static admittance of 0,3 to 1,9ml (Katz, 1994:248). Those with abnormal tympanograms or other external or middle ear pathology were referred for medical management.

3.4.1.3. Age

Subjects over the age of 55 years were excluded from the study as OAE amplitude is known to become unreliable and decrease after the age of 60 years (Hall, 2000:172; Bonfils, Bertrand & Uziel, 1988, cited in Vendatam & Musiek, 1991:441). OAEs have been found to be present in approximately 100 percent of normal subjects until the age of 60 years. After this age the incidence of the TEOAEs and DPOAEs tend to fall to 35 percent (Bonfils et al., 1988, cited in Vendatam & Musiek, 1991:441). Subjects that were available for testing and who were thus chosen were those between the ages of 18 and 55 years.

3.4.1.4. History of noise exposure and ear pathology

For the test group a further important criterion for selection was a history of at least one year of exposure to noise. Permanent damage to the outer hair cells of the cochlea occurs after one year of noise exposure (Clark & Bohne, 1999:2). The subjects had not been exposed to noise for at least 48 hours prior to the testing. This was to exclude the possibility of the presence of temporary threshold shifts which have been shown to decrease the amplitude of the emission (Hall, 2000:496). No history of industrial noise exposure was reported for the normative group. It was not feasible to exclude subjects in the normative group based on recreational noise exposure.

A case history was used to obtain information regarding the subject's history. The case history form can be viewed in Appendix A. It covered infectious diseases, traditionally treated with ototoxic medications including Malaria and Tuberculosis. A family history of congenital hearing loss and a personal history of hearing related difficulties e.g. tinnitis or middle ear pathology, further excluded the subject from taking part in the study. A history of job descriptions and exposure to noise was gathered. For the test group, the subjects were required to have worked in noise for at least one year (Clark & Bohne, 1999:2). The case history was used informally and not with a view of analyzing it statistically.

3.4.2. Description of subjects

The population group investigated was male mineworkers between the ages of 18 and 55 years from a single mine. Each subject was chosen based on the presence of normal hearing acuity from the pure tone test results, and the absence of middle ear pathology from the immittance testing and a history of ototoxicity. Both groups had undergone their annual hearing screening within two days before the testing took place and were randomly selected to take part in the study. The test group did not return to work between the time of testing and the hearing screening. The subjects were then classified into two groups, namely the test and normative groups. The normative group consisted of male novice mineworkers who had not been exposed to noise in the work place. They were being considered for employment by the mine. The normative sample consisted of 17 novices (average age: 25.4 years) (n = 34 ears). This sample was chosen in order that the test data could be compared to that of data from a normative sample for validation purposes. The test group consisted of veteran mineworkers who were daily exposed to high levels of noise in the workplace. The test sample consisted of 107 South African mineworkers (average age: 38 years) (n = 214 ears) with an average of 11, 6 years of exposure to noise. **Table 3.1** indicates a summary of the characteristics of each group tested.

Table 3.1: The characteristics of each group of subjects

	Test Group (n=107)	Normative Group (n=17)
Hearing Acuity	Normal: 0 to 25 dBHL	Normal: 0 to 25 dBHL
External and middle ear functioning	Normal otoscopic examinations and immittance measurements	Normal otoscopic examinations and immittance measurements
Age	20 to 55 years, average age:38 years	18 to 25 years, average age: 25,4 years
History of noise exposure	Minimum 1 year exposure, maximum 38 years: average exposure 11.6 years	0 years of noise exposure in the workplace
Work experience	1 to 38 years	0 years

Subjects over the age of 55 years were excluded from the study as OAE amplitude is known to decrease after the age of 60 years (Bonfils et al., 1988, cited in Vendatam & Musiek, 1991:441). Those subjects between the ages of 18 and 55 years were tested.

Figure 3.1 indicates the distribution of the age of the subjects. The majority of the test subjects were between the ages of 20 and 29 years. The normative group was between the ages of 18 and 25 years. The majority of the subjects from both groups fell within the 23 to 25 year age group and the average age was 25.4 years.

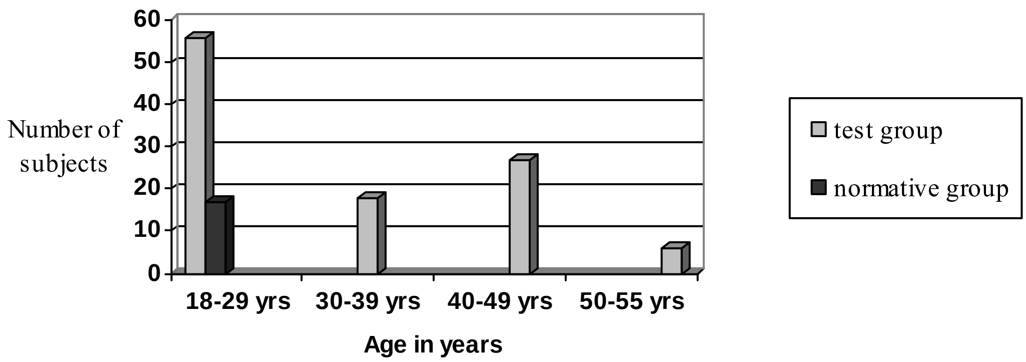

Figure 3.1: Distribution of age of subjects

3.5. Apparatus and material

The apparatus and materials used for subject selection, data gathering and analysis are discussed in the proceeding sections.

3.5.1. Apparatus and material for subject selection

The apparatus and materials used for subject selection were both electronic and manual in nature. These consisted of a case history, audiometric and immittance testing.

3.5.1.1. Materials for case history

A case history form is provided in Appendix A. It utilized both open-ended and close-ended type questions. With the test form, the case history formed one document for each subject. It was not analyzed statistically. Demographic information (age, sex) was initially requested. Further questions that were compiled related to the variables contained in the aims of the study (http://faculty.ncwc.edu, 2004). This was with a view to exclude subjects from the testing procedures should their histories contain factors which could influence the results of the study. Such factors included a history of ototoxic drug use and diseases such as malaria.

3.5.1.2. Apparatus and materials for audiometric testing

For determining the audiometric thresholds, the Madsen OB822 was used. The audiometer was calibrated on 30 July 2001 just before the gathering of data. Testing took place in an SABS approved soundproof booth. The results were depicted on a standard audiogram. (See appendix B for the calibration certificates). Standard headphones were used.

3.5.1.3. Apparatus for otoscopic examination

A battery operated Welch Allen otoscope was utilized to perform the otoscopic examinations.

3.5.1.4. Apparatus and materials for immittance measurements

For immittance measurements a calibrated SI 38 and Beltone 200 were used. The immittance equipment was calibrated on 30 July 2001 and 15 August 2001 respectively before the gathering of the data commenced. (See appendix B for the calibration certificates). The probe tips which were provided with each immittance machine were used and sterilized in Milton's® sterilizing solution after use. The results were recorded on the same test form as that used for the other data capturing.

3.5.1.5. Apparatus and material for data gathering

Two machines were used to capture the data for the OAE testing. This was necessary to measure inter-test and inter-tester reliability which was one of the sub-aims of the research project. The test settings did not differ between the machines.

Machine one was the Biologic® Scout Sport system running off a Mercer Pentium II computer. The data obtained can be downloaded onto any computer for analysis. The Scout Sport system uses an Etymotic ER-10C probe microphone measurement system without filters on the probe.

Machine two was the Biologic® Audinet system. This system differs from the first in that a laptop is not a necessary accessory when testing, and the probe has two filters. The filters aid in decreasing the amount of ambient noise. According to the manufacturer, this can result in slight, but normally not significant, differences in OAE recordings between the two instruments (Biologic Systems, 2002). A laptop was used with the Audinet system in order to replicate the test procedures as accurately as possible.

Each foam probe tip was sterilized in Milton's® sterilizing solution after use. The foam tips were standard adult probe tips obtained from Biologic® Systems.

3.5.1.6. Apparatus and material for the analysis of data

All the data, both the audiometric and OAE test results, was formulated onto Excel spreadsheets as requested by the statistics department and analyzed according to the various test parameters. The CSIR and the University of Pretoria's statistics department completed the analysis. Statistical procedures used included the use of descriptive statistics such as variance, standard deviation, correlation and regression, chi squared analysis, probabilities and Fisher's Exact test (Howell, 1995:1).

3.6. Procedure

Various procedures were used to gather the necessary data, both from the subjects themselves and from the OAE testing. These procedures are discussed in the following sections.

3.6.1. Procedure for the selection of subjects

Subjects were randomly drawn from the routine hearing screening based on the results of their audiograms. This screening took place at the Occupational Health Center at East Driefontein goldmine, and was completed by the nursing staff. The mine nursing sister was asked to initially screen the subjects for a history of noise exposure and previous infections which would have been treated with ototoxic drugs e.g. malaria and tuberculosis. This information was requested informally from the subject, during a standard interview with the nursing staff. The subjects were excluded from the study if the nurse found them to have had ototoxic medication or previous middle ear pathology. The prospective subjects were requested to attend the further testing at the East Driefontein Audiology Clinic the following week. An interpreter employed by the mine, obtained consent from the test subject and completed an additional short case history with each subject. (See appendix A for the case history and consent forms). The interpreter explained the test procedures and aim of the study using the consent form. The subject was requested to take part in the study and any questions were answered. The case history covered a history of noise exposure, use of ear protection and a history of infectious diseases treated with ototoxic drugs. These questions were repeated, even though the nursing staff had asked them before, in order to ensure that the subjects had understood and answered the questions correctly. This is due to the fact that many languages are spoken on the mine and misunderstandings often occur. Confidentiality was ensured by the use of subject numbers and no names were recorded. Each subject then underwent a bilateral otoscopic examination by the audiologist. A battery operated Welch Allen otoscope was used to examine the external auditory meatus. Any obstructions such as cerumen or growths were noted and the subject returned to the medical officer for further examination. In addition, subjects with red tympanic membranes or perforations of the tympanic membrane were sent for evaluation to the medical officer. Immittance measures were obtained on those subjects with clear otoscopic examinations. Subjects with abnormal tympanograms were referred for immediate medical management. The audiologist repeated the audiometric testing with those subjects with normal immittance measures. Normal immittance measures included Type A tympanograms. These were identified by a middle ear pressure of –100 to +100daPa, ear canal volumes of 0,65 to 1,75ml and a static admittance of 0,3 to 1,9ml (Katz, 1994:284). All other results were interpreted as abnormal and sent for medical management.

3.6.2. Procedure for the gathering of data

Both groups of subjects underwent an identical battery of OAE tests. The OAE testing took place in a quiet room. All environmental noise sources were eliminated as far as possible. Sources of environmental noise included that of telephone and cell phones, lawnmowers, plumbing and subjects awaiting testing. Telephones were removed from the test area, subjects were requested to remain quiet and all taps were turned off during testing. The lawnmower operators were requested to return at a later time. Subjects were requested to remain silent and minimize facial and bodily movements during the testing (Baer & Hall, 1992:20). The subject was seated next to the test equipment and requested to remain quiet during the testing. The probe was then attached to the subject's lapel to avoid it from moving during the testing. An appropriate size probe tip was selected according to the subject's ear canal size. A snug fit was ensured. A good probe fit was required to ensure that ambient noise was decreased and that a relatively flat frequency response was achieved for the recording microphone and the eliciting stimulus. This should be obtained over the range of frequencies tested i.e. 300 Hz to 8000 Hz (Probst et al., 1991:2030). The noise levels in the ear canal were verified using the calibration phase of the test, obtaining a probe stability value of more than 80 percent before testing commenced. The Biologic® system for both machines routinely uses 80 percent probe stability whereas other researchers indicate that 70 percent stability or more is adequate. This is to ensure test validity (Lonsbury-Martin et al., 1994:173). All tests were completed on one ear before the probe was removed from the first ear to test the second ear. The subject moved to the second set of test equipment and each test was repeated by the second audiologist, in a similar environment, on the same day, to evaluate inter-test reliability.

Transient otoacoustic emission and distortion product otoacoustic emission screening and diagnostic tests were performed. It is important to investigate both types of OAEs and the different tests in order to select which test is more appropriate for screening versus diagnostic purposes within this population group and for the purposes of the mine (Probst & Harris, 1993:858).The diagnostic TEOAE test and the TEOAE screening test, with the parameter of 70 percent reproducibility at three out of three frequencies for a pass, were chosen (Biologic Systems, 2002). The TEOAE screening test was performed first on both the right and left ear of each subject, followed by the TEOAE diagnostic test on each ear. The frequencies used to measure the pass/fail result for the TEOAE screening test were two KHz, three KHz and four KHz. A pass/fail result was obtained with this test using a broad band analysis (Biologic Systems, 2002). The TEOAE diagnostic test was subsequently performed. The TEOAE tracing from the diagnostic test was analyzed into a narrow band analysis by the Biologic® equipment. In this way it is possible to conclude from the diagnostic version whether cochlear damage is present in certain frequency bands (Tognola et al., 1999:248). The DPOAE tests were then performed in the same manner as the TEOAE tests. The DPOAE tests consisted of the DPOAE two to eight KHz diagnostic test and the DPOAE two to five KHz screening test. The DPOAE screening test was performed first followed by the DPOAE diagnostic test on both the subjects' left and right ears. The DPOAE screening test required the distortion product to be six dB above the noise floor at three out of four of the test frequencies to indicate a pass result (Biologic Systems, 2002). Instead of obtaining an overall pass or fail result as for the DPOAE screening test, the results of the DPOAE diagnostic test were analyzed at each test frequency for more diagnostic purposes. The DPOAE diagnostic test also required the signal (DP) to be at least six dBs above the noise floor to indicate a present distortion product. The results were analyzed at each frequency in order to establish any emerging patterns such as notching in the three to four KHz region. The test parameters set by the Biologic® system for each test remained unchanged. To evoke the DPOAE, two stimulus tones of separate frequencies were presented to the test ear. The first frequency is known as the f1 primary tone and is the lower frequency stimulus. F2 is the higher frequency stimulus or primary tone (Lonsbury-Martin et al., 1991:969). The ratio of f2/f1 was kept constant at 1.2 with the f1 equal to 65 dB and the f2 equal to 55 dB (Hall & Mueller, 1997:247). These stimulus conditions have previously resulted in the greatest separation between normal and abnormal ears (Gorga et al., 1997:440). The ratio of f2/f1 being set at 1.2 produces the largest distortion products (Gaskill & Brown, 1990, cited in Gorga et al., 1997:440). The DPOAEs were measured at the preset frequencies of 2f1-f2, ranging from two to eight KHz. The most prominent DPOAE in mammals is obtained at 2f1-f2 with the ratio of f2/f1 equal to 1.2 (Probst & Hauser, 1990:236; Lonsbury-Martin et al., 1997:89). The geometric mean of the frequencies and the values of f1 and f2 are displayed in **Table 3.2**. The amplitude of the DP obtained also depended on the level difference of the primary tones. The level of f1 is referred to as L1 and the level of f2 as L2 (Lonsbury-Martin et al., 1997:87). L1 greater than L2 by ten dBs is most suitable for the detection of DPOAEs with L1 equal to 65 dBs and L2 equal to 55 dBs. These values sensitize the DP to the noise damaged cochlear and a DP with a larger amplitude which is easily detectable, is obtained (Sutton et al., 1994:161; Gaskill & Brown, 1993:397). In addition, Stover, Gorga, Neely & Montoya (1996) cited in Gorga et al (1997:441) indicated that this stimulus condition results in the greatest separation of normal versus impaired ears. More DPOAEs are recorded with L1 greater than L2 as compared to a ratio of L1 equal to L2.

The DPOAE tests were analyzed according to the amplitude of the DPOAE. Graphically this is seen as a DP gram where the frequencies change and the loudness levels are kept constant. The DP gram is plotted as a function of the frequency of the primary tones across the range of frequencies being tested (Lonsbury-Martin et al., 1997:89). The advantage of using the DP gram is that it describes "the detailed frequency pattern of a cochlear impairment" (Lonsbury-Martin et al., 1997:89). DPOAE amplitude of six dBs or more above the level of the noise floor was accepted as a present DP (Hall & Mueller, 1997:255; Probst & Hauser, 1990:238). The majority of researchers have used a distortion product to signal-to-noise ratio of three to five dBs (Lonsbury Martin et al., 1990). Robinette and Glattke (1997:234) however, point out that if the response is only slightly above the noise floor then the response may be a statistical artifact. Therefore it is of importance to choose an adequate dB level to indicate the presence of a DPOAE. According to Hall (2000:104), test sensitivity is adequate if there is more than a five dB difference between the DPOAE and the noise floor with noise floor values being at a minimum. A difference of six dBs was chosen for this study in order to have an adequate dB level to indicate a present DPOAE as well as to increase the test's sensitivity (Vedantam & Musiek, 1991:441). Gorga et al., (1993:2050) recommended that both the amplitude of the DPOAE and the distortion product to signal-to-noise ratio levels (DP/NF) should be used in conjunction to differentiate between normal and impaired subjects. Therefore the DP values and noise floor levels were compared against the normative data from the Vanderbijlt 95th-5th percentile for 65/55, study (cited in Hall

& Mueller, 1997:256). The Vanderbijlt study used the identical test parameters that are being used for the present study. **Table 3.2** indicates the primary levels, f1 and f2, with the geometric mean of the screening DPOAE test utilized. **Table 3.3** indicates the primary levels, f1 and f2, with the geometric mean of the diagnostic DPOAE test utilized.

Table 3.2: Primary tones and geometric means of the DPOAE screening test

2-5KHz DPOAE screening test	Hz	Hz	Hz	Hz
Primary tone f1	4170	3327	2483	1687
Primary tone f2	5014	3983	2999	2015
Geometric mean	4573	3640	2729	1844

Table 3.3: Primary tones and geometric means of the DPOAE diagnostic test

2-8KHz DPOAE diagnostic test	Hz	Hz	Hz	Hz	Hz
Primary tone f1	6654	4686	3327	2343	1640
Primary tone f2	7966	5623	3983	2811	1968
Geometric mean	7280	5133	3640	2566	1797

The analysis of the TEOAE tests differs from that of the DPOAE tests. The reproducibility percentage has been the standard and most accurate TEOAE measure used to date (Gorga et al., 1993:2051). Controversy in the literature exists over which value is sufficient to indicate the presence of a transient evoked emission. Prieve, Gorga, Schmidt, Neely, Peters, Schultes and Jesteadt (1993) cited in Hall (2000:152) indicated that a 60 percent reproducibility is sufficient whereas Vedantam and Musiek (1991:441) used 70 percent. However the reproducibility value should not be used in isolation (Hall, 2000:151, Lonsbury-Martin et al., 1991:971). The amplitude of the transient emission should be considered in conjunction with the reproducibility value at each octave band. Vedantam and Musiek (1991:441) used an amplitude of six dBs with Lonsbury-Martin et al., (1991:971) using an amplitude of five dBs. In the mining population, where the prevalence of NIHL is prominent, a high sensitivity is required in testing. Sensitivity is determined by the procedure correctly identifying a significant hearing impairment (Katz, 1994:478). To increase the sensitivity of the testing which is required when screening for hearing loss, a 70 percent reproducibility value and a TEOAE amplitude of six dBs was chosen for this study to indicate the presence of a transient emission. The Biologic® system differentiates the overall TEOAE response into separate frequencies. Therefore a pass result was indicated by 70 percent or more reproducibility with a transient emission to noise floor ratio of at least six dBs at a test frequency. This was to be obtained at each frequency, one KHz to four KHz on the diagnostic test and at three of the test frequencies (two, three and four KHz) for the screening TEOAE test to indicate a present TEOAE (Vendantam & Musiek, 1991:441).

3.6.3. Procedure for the recording of data

Each subject was supplied with a number to ensure confidentiality. Their work number and date of birth were recorded on the case history form. The subject's answers to the case history questions as well as the consent form were added to that of the test results form. As each test was completed, the results of the pure tone tests, both screening and repeat tests, the immittance measures and the results of the otoscopic examinations were recorded on the test form. As the operator completed each OAE test, the test was recorded on the subject's test form. The OAE data was saved onto each computer's hard drive as well as onto floppy disks. The files were labeled accordingly.

3.6.4. Procedure for the analysis of data

The data was sent electronically to the relevant department of statistics, both at the CSIR and University of Pretoria. The raw data was captured in the form of excel spreadsheets as requested by the statistician. Bar graphs and tables were generated to pictorially depict the outcome of the testing. The prevalence of OAEs in this population as well as the sensitivity and specificity of the test procedures and inter-test reliability were determined using descriptive statistical procedures. These included variance, standard deviation, correlation and regression, chi squared analysis, probabilities and Fisher's Exact test (Howell, 1995:1). The DPOAE and TEOAE tests were examined separately as different analysis criteria exist for each, to determine the outcome.

3.7 Summary

The chosen research design was a cross sectional survey. The subjects for the study were randomly chosen from two groups of mine workers; those who had been employed by the mine for longer than one year (n=107) and those who were novice mine workers (n=17). Subjects were between the ages of 18 and 55 years. The materials for the subject selection consisted of a case history, pure tone screening tests, otoscopic examinations and immittance measures. All subjects had hearing thresholds within normal limits, normal immittance measures and normal otoscopic examinations. The apparatus for the data collection consisted of the Biologic® Audinet system and the Biologic® Scout Sport system and four OAE tests per subject were completed. These tests consisted of both screening and diagnostic TEOAE and

DPOAE tests. The tests were repeated by a second audiologist on the same day. The data was then submitted to the University of Pretoria and the CSIR statistics department and analyzed utilizing descriptive statistical procedures.

Chapter 4: Results and Discussion

The purpose of this chapter is to present all the results obtained from the experimental phase of the research conducted. A discussion of each result is included.

4.1. Introduction

In 1998 the National Institute for Occupational Safety and Health (NIOSH), in the United States, estimated that the number of workers exposed to noise has increased by over 30 percent since 1992 (NIOSH,1998:1). Long-term noise exposure is one of the primary causes of cochlear damage and results in permanent changes within the auditory system. It has been shown that the OHCs of the cochlea, responsible for generating OAEs, are extremely sensitive to noise damage (Kowalska & Sulkowski, 1997:453). Therefore OAEs provide evidence concerning the normal or abnormal functioning of the cochlea and have become widely used clinically. Although emission testing has provided new insights into common hearing difficulties such as NIHL, the use of OAEs as a screening tool in the adult population has yet to be fully investigated and approved. There are still practical and theoretical issues to be resolved before OAEs can be implemented as a screening tool (Durrant, 1992:42).

The aim of the present study was to evaluate whether OAE testing is a feasible screening method for the early detection of NIHL in South African mineworkers. OAEs provide site specific information of cochlear mechanics and may therefore be useful in the early detection of NIHL. Research has indicated that OAEs specifically assess the status of the outer hair cells of the cochlea which are sensitive to cochlear dysfunction caused by noise exposure (Engdahl, 1996:72; Eddins et al., 1999:120; Attias et al., 1995:612; Engdahl & Kemp, 1996:1573; Sutton et al., 1994:161). The sub-aims of the study focused firstly on the characteristics and prevalence of both

DPOAEs and TEOAEs obtained from a test group (n=212) of mineworkers exposed to noise and from a non-exposed normative sample (n=34). Further sub-aims considered the effect of age and length of noise exposure on the OAE tracings, and the sensitivity and specificity of the various tests. Lastly inter-test reliability was also considered. For such a specific purpose as that of detecting NIHL, an ideal test for this population would be highly sensitive and specific as well as quick and easy to perform. OAEs are able to detect the onset of developing hearing losses such as NIHL and therefore may contribute to prevention and management of NIHL within hearing conservation programs (Lonsbury-Martin, 1999). This chapter considers the results of the study in the light of previous research findings with each sub-aim being discussed separately.

4.2. Prevalence of TEOAEs

The first sub-aim of this study was to ascertain the prevalence of TEOAE's in both the non-exposed novice and noise exposed population of mineworkers, with normal audiometric thresholds.

4.2.1. Prevalence of TEOAEs in the normal non-exposed group of subjects.

The following graphs indicate the prevalence obtained from the TEOAE screening and diagnostic tests completed on the normal non-exposed group of subjects. Due to the differences in the results between the two machines used, the results from each machine are depicted separately. The figures depict the percentage of TEOAEs obtained from the normal non-exposed group for both the diagnostic and screening TEOAE tests.

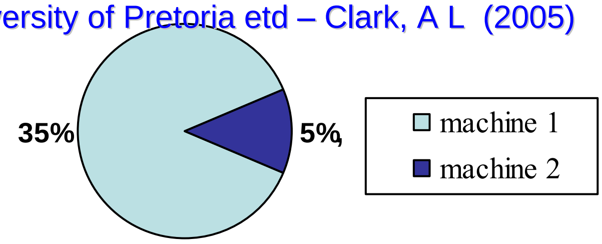

Figure 4.1: Prevalence of TEOAEs as determined by the TEOAE screening test in the normal non-exposed group

Figure 4.1 indicates that a higher prevalence of TEOAEs was obtained with machine one as compared to machine two. TEOAEs were present in 35 percent (n=12) of the normal non-exposed group using machine one. Only five percent (n=two) of the normal non-exposed group obtained present transient emissions with machine two. The remaining subjects failed the TEOAE screening test.

Figure 4.2 indicates the prevalence of transient emissions in the normative group of subjects obtained from the diagnostic TEOAE test. Once again the results obtained with each machine are depicted separately.

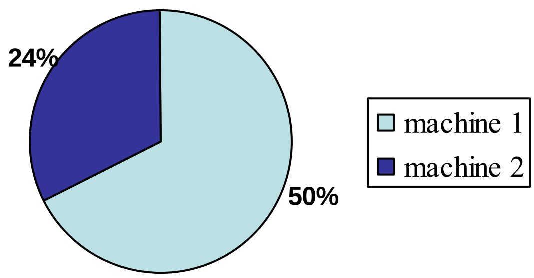

Figure 4.2: Prevalence of TEOAEs as determined by the TEOAE diagnostic test in the normal non-exposed group

Figure 4.2 indicates that 50 percent of the subjects passed the TEOAE diagnostic test with machine one and 24 percent prevalence was obtained with machine two. Once again machine one obtained a higher percentage of present transient emissions for this group as opposed to machine two. From these graphs it is evident that the prevalence of transient emissions in the normal non-exposed group of subjects was low and neither machine obtained a percentage within the range as reported by the literature (Lonsbury-Martin et al., 1994:171). It was expected that 95 percent to 100 percent prevalence would be obtained as indicated by previous research in a normal non-exposed population (Lucertini et al., 1996:86; Bonfils et al., 1988:27). Although researchers have found absent OAEs in normal, non-exposed ears, the incidence has been less than what the results of this study have indicated. Co-exposure to other damaging agents such as recreational noise, ototoxic drugs, and solvents, unknown within this group, cannot be ruled out and may have had an indirect impact on the results (American College of Occupational and Environmental Medicine, 2002:2). In addition the low prevalence and discrepancy existing between the two machines indicates that these TEOAE tests and the parameters used may not be adequate in accurately differentiating between normal and noise exposed ears.

However the acquisition of a normative sample is important for determining the sensitivity and specificity of a screening tool and thereby enabling the clinician to make accurate referrals.

4.2.2 Prevalence of TEOAEs in the noise exposed group of subjects.

TEOAEs have been found to be reduced or absent in ears exhibiting cochlear impairment and hearing loss (Lonsbury-Martin et al., 1994:175). TEOAEs are also sensitive to the early onset of hearing problems. Although this test group all demonstrated normal audiometric results, the prevalence of TEOAEs was low attesting to the fact of possible early onset of hearing loss. The prevalence obtained from this group of subjects was generally lower than for the normal non-exposed group. **Figure 4.3** indicates the overall prevalence of TEOAEs obtained for the noise-exposed test group. The prevalence is based on the percentage of present TEOAEs obtained at four KHz for each test.

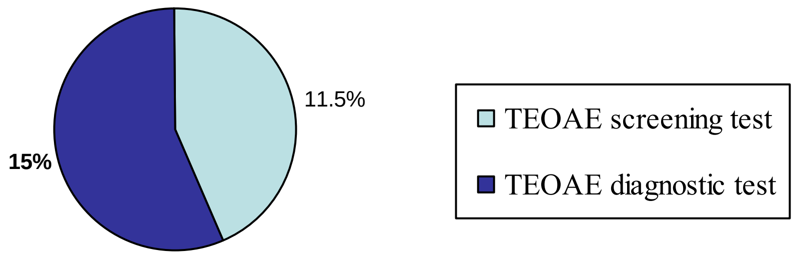

Figure 4.3: Prevalence of TEOAEs in the noise-exposed test subjects

As a pass result at four KHz was required to indicate an overall pass for the subject, it can thus be ascertained that the overall prevalence of TEOAEs for the test subjects was 11.5 percent for the TEOAE screening test and 15 percent for the TEOAE diagnostic test. Thus in general the prevalence for the noise-exposed test group was lower than for the normal non-exposed group of subjects; except for the results from the TEOAE screening test from machine one (five percent prevalence).

Figure 4.4 indicates the prevalence of the transient emission for the screening TEOAE test in this group of subjects. The results from both machines are depicted together as a large discrepancy between the two machines did not exist as for the normative group. The machines provided response validation, stimulus verification and noise rejection to ensure valid results. Although an overall pass or fail result is obtained, the Biologic system® analyses the transient response not only into an overall pass/fail broadband result but additionally shows an analysis into separate narrow band frequency regions.

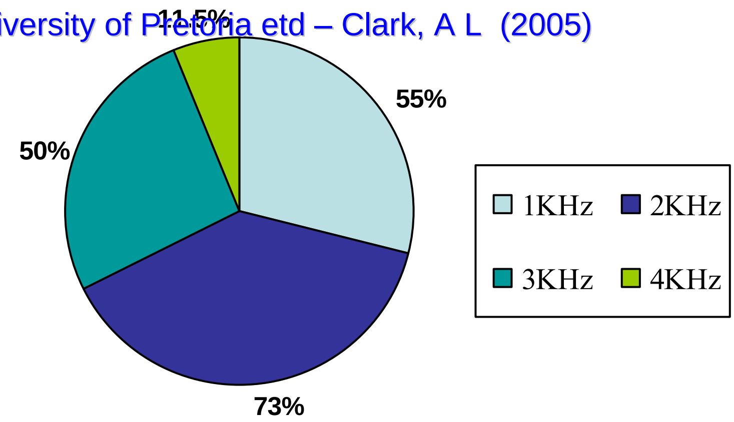

Figure 4.4: Prevalence of TEOAEs as determined by the TEOAE screening test in noise-exposed test subjects

In **Figure 4.4** the prevalence of the transient emission is depicted at each frequency. The figure shows that as the frequency increased so the prevalence of the emission decreased. At one KHz the prevalence was 55 percent and this decreased to 11 percent at four KHz. However at two KHz the prevalence was higher than at one KHz.

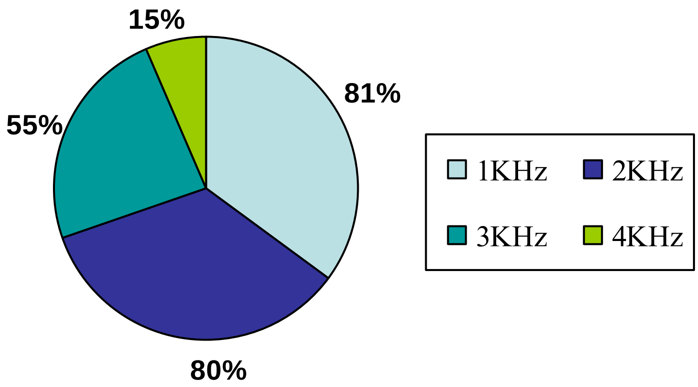

Figure 4.5: Prevalence of TEOAEs as determined by the TEOAE diagnostic test in noise-exposed test subjects

Figure 4.5 depicts the prevalence of present transient emissions for the test group of subjects as obtained from the TEOAE diagnostic test. An overall pass or fail result is obtained with the diagnostic TEOAE test. The Biologic system® is also able to analyze the broadband stimulus into separate bandwidths. Thus the figure depicts the prevalence of the transient emission at each frequency. Here the prevalence of the emission decreased as the frequency of the stimulus increased with the prevalence being 81 percent at one KHz and 15 percent at four KHz. A higher overall prevalence was obtained by the TEOAE diagnostic test (15 percent) as compared to that of the screening test (11.5 percent) for these subjects. A similar pattern was obtained for both tests however, that is that the prevalence of the emission decreased as the frequency of the input increased.

These findings for the noise-exposed test group are consistent with those found in the literature, where noise-induced high frequency hearing loss has been associated with a decrease or absence of emissions around the region of four KHz (Probst et al., 1991:2048). In addition Attias et al., (1995:612) found a decrease in emissions in the high frequencies in noise exposed ears with normal audiometric results. TEOAE components have been observed to decrease by frequency as frequency increases. TEOAEs are most robust at one to two KHz and become typically smaller above 4.5 KHz (Lonsbury-Martin et al., 1994:171). This was similarly observed in this present study for the TEOAE tests for the noise exposed group. The highest prevalence (73 percent to 80 percent) for both the screening and diagnostic tests was obtained at two KHz. This may be related to the fundamental frequency of the noise the workers are exposed to daily. Although the region of three to four KHz has been used to differentiate between normal and abnormal ears, other frequency regions may be more applicable with this population group due to the low prevalence of tracings at three to four KHz in the normative sample. TEOAE testing in this population group may not be sufficiently accurate in differentiating between normal and noise-exposed ears due to the low prevalence of TEOAEs obtained in the normal non-exposed group of subjects. It may also be true that the TEOAE tests are too sensitive to be used within a field procedure and more applicable within a diagnostic test setting. The test parameters used for the TEOAE tests may also need to be reevaluated to obtain accurate measures of sensitivity and specificity for this population group.

4.3. Characteristics of TEOAEs in the test groups

The characteristics of TEOAEs are generally reflected by the reproducibility and amplitude values obtained. Studies have observed that noise exposure reduces OAE amplitudes especially between three KHz and six KHz where the maximum effect of noise damage is seen on an audiogram (Kemp, 1982:195; Vinck et al., 1999:47). In order to describe further characteristics of the transient echoes obtained, the TEOAE data was analyzed by obtaining the mean values for the amplitude of the transient echo and the reproducibility values obtained, at two KHz, three KHz and four KHz. Tables 4.1 and 4.2 indicate the mean values obtained at each frequency, for the left and right ears separately, for the screening and diagnostic TEOAE tests. The standard deviations are shown in brackets in Ta**ble 4.2.**

Table 4.1: The means of the TEOAE screening test obtained in the noise-exposed test group (n = 212) and non-exposed normal group (n = 34)

Noise-exposed test group	Frequency (KHz)	TE amplitude in decibels	Reproducibility values in %
Right ears	2 KHz	10 dB	81 %
n = 212	3 KHz	9 db	76 %
	4 KHz	**2 dB**	**32 %**
Left ears	2 KHz	10 dB	76 %
n = 212	3 KHz	8 dB	74 %
	4 KHz	**2 dB**	**33 %**
Non-exposed group	Frequency (KHz)	TE amplitude in decibels	Reproducibility values in %
Right ears	2 KHz	15 dB	92 %
n = 34	3 KHz	13 dB	90 %
	4 KHz	5 dB	59 %
Left ears	2 KHz	14 dB	90 %
n = 34	3 KHz	15 dB	94 %
	4 KHz	**5 dB**	**56 %**

Table 4.1 indicates the results obtained for the screening TEOAE test. The average reproducibility values at each frequency are shown. Therefore the average reproducibility obtained for the noise-exposed group, for the right ears, at two KHz was 81 percent. A pass result is specified by 70 percent or more reproducibility at three out of three, 3/3, of the selected frequencies two KHz, three KHz and four KHz for the screening test (Biologic Systems, 2002). Although a broad band stimulus is used, the Biologic® system depicts an analysis of the emission at each frequency band. Thus the mean values calculated in **Table 4.1**, indicated that a pass result was

generally obtained at two KHz and three KHz (>70%) but not at four KHz (< 70%) for both groups (Biologic Systems, 2002). A decrease in the dB level of the TE amplitude as the frequency increases is also evident according to the results depicted on the table. For example in the test group, the TE amplitude decreased from ten dBs at two KHz to two dBs at four KHz for the right ears. This is highlighted in the first part on the table. The same result is shown for the left ears of the noise exposed group. The TEOAE amplitude similarly decreased for the non-exposed group. The amplitude at two KHz was 15 dB and decreased to five dB at four KHz for this group's right ears. Therefore although the average reproducibility in the normal non-exposed group was higher than that of the noise-exposed group, the reproducibility was still below 70 percent indicating an absent TEOAE result. This test may therefore not be sufficiently reliable in differentiating between normal and noise-exposed ears.

Table 4.2: The means obtained in the noise exposed test group (n= 212) and non-exposed normal group (n=34) for the diagnostic TEOAE test

Noise exposed test group	Frequency (KHz)	TE amplitude in decibels (dB)	Reproducibility values in %
Right ears	2 KHz	11 dB (5)	86 % (18)
n = 212	3 KHz	10 dB (5)	83 % (19)
	4 KHz	3 dB (3)	39 % (29)
Left ears	2 KHz	11 dB (5.8)	84 % (19)
n =212	3 KHz	9 dB (50)	83 % (19)
	4 KHz	3 dB (3)	40 % (28)
Non-exposed normal group	Frequency (KHz)	TE amplitude in decibels (dB)	Reproducibility values in %
Right ears	2 KHz	16 dB (5.7)	91 % (13)
n =34	3 KHz	13 dB (4.9)	93 % (6)
	4 KHz	5 dB (3)	61 % (24)
Left ears	2 KHz	14 dB (5.6)	92 % (8)
n =34	3 KHz	16 dB (4)	96 % (3.8)
	4 KHz	5 dB (3)	63 % (21)

Table 4.2 indicates the results for the TEOAE diagnostic test for both groups of subjects. In **Table 4.2** similar results were obtained as for the TEOAE screening test. Once again the reduction in both the reproducibility values and TE amplitude is evident as the frequency increases for both sets of subjects. At two KHz the average reproducibility was 86 percent with the TE amplitude being 11dB, for the right ears of the test group. This decreased in the same set of ears to 39 percent reproducibility and TE amplitude of three dB at four KHz. Thus the group mean on the response amplitude/reproducibility values, showed a systematic decrease in response level from two KHz to four KHz. The decline is most evident in the noise-exposed subjects.

This trend corresponds with numerous other reports in the literature (Bonfils & Uziel, 1989:326; Reshef et al., 1993:387; Kowalska & Sulkowski, 1997:455; Vinck et al., 1999:47). Therefore the reduction in the TEOAE amplitudes infers that OHC damage has occurred due to noise exposure, despite normal audiometric hearing thresholds. This was primarily observed for the four KHz frequency band for both groups of subjects.

In addition **Table 4.2** reflects the standard deviations obtained. The standard deviation increased towards four KHz. Thus a large variation is indicated at four KHz for both groups, with the variation being larger for the test group. Although the analysis was not statistically significant, due to the large variances found, the trend observed indicated that TEOAEs tend to decrease as the frequency increases (Kowalska & Sulkowski, 1997:455; Vinck et al., 1999:47). Similar results were obtained for both the screening and diagnostic TEOAE tests. Although the Biologic® system indicates the emission at each frequency in terms of reproducibility and signal to noise (S/N) ratio it must be taken into account that these levels at one given frequency does not provide a perfect indication of the action of the cochlea at those specific frequency points (Lonsbury-Martin et al., 1997:171). However for both the left and right ears of the test group the best response was obtained at two KHz. Pass results (>70% reproducibility and > six dB amplitude values) were obtained at two and three KHz but none at four KHz. In reality this amounted to an overall fail result for the test subjects on the TEOAE tests. Thus both the amplitude and reproducibility values steadily decreased with increased frequency. This is substantiated by Vinck et al., (1999:44) who established that reproducibility scores and signal to noise (S/N) ratios were most sensitive to the effects of noise at four KHz as compared to other frequency regions. Kowalska and Sulkowski (1997:448) reported findings in hearing impaired subjects of the highest TEOAE response being at one and two KHz. The tracing decreased at the higher frequencies in particular at four KHz. Similar results were found in their control group with the greater responses being at one and two KHz and decreasing at four and five KHz. However the decline was significantly more evident in their group of test subjects as opposed to the normative sample used. Prieve et al., (1993:3317), also reported that TEOAEs best separate normal and damaged ears at two and four KHz. Bicciolo et al., (1993:505) found abnormal OAEs in 48 percent of subjects working in noise who had normal audiograms. The lack of emissions was especially evident in the higher frequencies. The present study also found that emissions tended to be absent in the higher frequencies. Therefore it may be concluded that OAEs are highly sensitive in detecting early cochlear damage. Thus the results from the present study indicated a higher prevalence of TEOAEs in the lower frequency regions (one and two KHz) with the TEOAEs systematically decreasing as the stimulus frequency increased.

In the presence of normal pure tone audiometric thresholds for these noise-exposed subjects these results may indicate presymptomatic cochlear damage. Similar trends have been found in the literature where reduced amplitude of the transient echo indicates hearing loss or presymptomatic cochlear damage (Fabiani, 1993:132; Attias et al., 1995:612; Reshef et al., 1993:123). With regards to the non-exposed group, Musiek et al., cited in Tognola et al., (1999:248) reported that less than 50 percent of normal ears showed a presence of TEOAEs above four KHz. Musiek et al., cited in Tognola et al., (1999:248) did not however indicate what reproducibility level was used in their study to differentiate between an absent or present OAE tracing. Tognola et al., (1999:248) however indicated that 60 percent reproducibility was sufficient in differentiating between normal and impaired ears. Absent TEOAEs were also found in this frequency region of four KHz in the present study. However a higher percent reproducibility was used (70 percent). This may have caused the TEOAE tests to be too sensitive than necessary for the requirements of a screening program within the target population, therefore resulting in the TEOAE tests not being reliable in differentiating between the two groups. However the parameters used within the test protocol could be modified and thus allow TEOAEs to be a more reliable method for identifying NIHL especially within this population group of mineworkers. The effect of sociocusis should not be overlooked when considering the results from the non-exposed group. The exposure to previous recreational noise sources is unknown in this group and can have an effect on the OAE outcome (Henderson & Hamernick, 1995:513; Franks & Morata, 1996, cited in NIOSH, 1998:2). Nevertheless research has shown that TEOAEs are helpful in objectively identifying and confirming cochlear dysfunction (Lucertini et al., 1996:79). Hotz et al., (1993:478), found that TEOAE's was a valid and reliable field procedure to use to detect early onset of NIHL. It needs to be remembered however that TEOAEs are less frequency specific than DPOAEs due to the overall functioning of the cochlea being tested. Other variables appear to have an additional impact on the decision making process in this study. The normative group exhibited cochlear dysfunction which may be attributable to the influence of recreational noise. Ferguson et al., (2000:125) found that the two KHz region was most affected by persons exposed to recreational noise. This however was not the case in this study, where four KHz appeared to be most affected. In addition, the impact of HIV on cochlear dynamics is unknown. New studies have tentatively concluded that there is a link between HIV/Aids and sensori-neural hearing loss. A prevalence of 23 percent of hearing loss was estimated, among HIV/Aids adult sufferers in Gauteng, South Africa. This study did not however include OAE testing (Khoza & Ross, 2002:26). In conclusion therefore the results from the TEOAE testing indicated a low prevalence of TEOAEs in both the noise-exposed and non-exposed groups. The TEOAE tracings decreased towards the higher frequency region of four KHz with the highest percentage of present TEOAEs being found at two KHz. TEOAE testing may therefore uncover the presence of subclinical cochlear damage. However for results to be conclusive additional research is required with regard to extraneous variables such as sociocusis, the impact of HIV/Aids and intrinsic variables such as the test parameters used for this population group.

4.4. The prevalence of Distortion Product OAEs

DPOAEs are present in 96 percent of audiometrically normal ears and disappear with hearing loss of 55 dBHL or more (Oeken & Muller, 1995:473). The remaining four percent is due to unknown causes.

4.4.1 The prevalence of Distortion Product OAEs in the normative group of subjects.

The following graph depicts the results obtained for the DPOAE tests in the normative group.

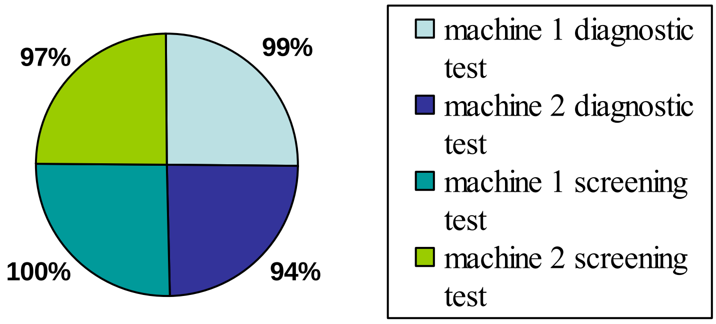

Figure 4.6: Prevalence of DPOAEs in the non-exposed normal group

Figure 4.6 depicts the prevalence of present DPOAEs for the non-exposed normal group of subjects for the screening and diagnostic DPOAE tests. The overall prevalence obtained for both diagnostic and screening tests was 100 percent for machine one with a 99 percent prevalence for machine two. Thus a higher prevalence was obtained for machine one for both the screening and diagnostic DPOAE tests as compared to the results from machine two. According to the chi squared analysis utilized, these results remain statistically insignificant partially due to the small number of subjects (n=34). However the prevalence of the DPOAEs fell within the normative data recorded in the literature, that of 96 percent.

4.4.1. <u>The prevalence of Distortion Product OAEs in the noise-exposed test group of subjects.</u>

Hearing within normal limits was obtained for the noise-exposed test group of subjects. This was the same group used to determine the prevalence of TEOAE's for the previous aims. Thus a high prevalence of DPOAEs was expected as DPOAEs only disappear or decrease with hearing loss greater that 55 dBHL (Oeken & Muller, 1995:473). The first figure below indicates the prevalence of the DP for the DPOAE screening test.

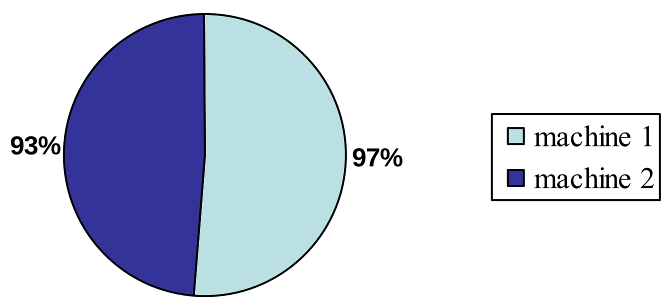

Figure 4.7: Prevalence of DPOAEs in the noise-exposed test subjects for the screening DPOAE test

The results as depicted in **Figure 4.7** indicated a higher prevalence of DPOAEs obtained from machine one (97 percent) as compared to machine two (93 percent).

The following figure depicts the prevalence obtained for the diagnostic DPOAE test.

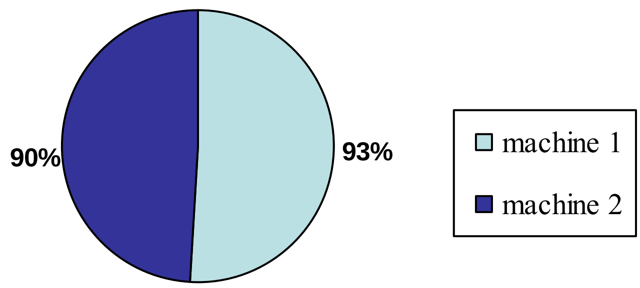

Figure 4.8: Prevalence of DPOAEs in the noise-exposed test subjects for the diagnostic DPOAE test

The results indicated by **Figure 4.8** once again showed a higher prevalence of DPOAEs for machine one as opposed to machine two. The percentage obtained for machine one was 93 and for machine two, 90 percent. Therefore for both the diagnostic and screening DPOAE tests, machine one obtained a higher percentage of present DPOAEs. The prevalence of the DPOAEs did not differ significantly between the two machines and the two types of tests used. Nevertheless in the presence of normal audiometric results, absent DPOAEs were evident in the noise-exposed group.

A lower prevalence of present DPs were obtained for the noise-exposed group as compared to the non-exposed group in the diagnostic test. The overall prevalence for the noise-exposed test group was 92 percent as opposed to that of 97 percent for the non-exposed group. The prevalence for the non-exposed group falls well within the prevalence of DPOAEs for normal ears reported in the literature that is 96 percent. As Ferguson et al., (2000:125) indicated the remaining percent may be attributed to social noise exposure or other variables. Similar findings were reported by Plinkert et al., (1999:367).

Still the results for the diagnostic DPOAE tests were statistically insignificant according to the chi squared analysis utilized.

4.5. Characteristics of DPOAEs in the noise exposed group of subjects

DPOAEs are characterized by their amplitude, level above the noise floor or DP-NF ratio. The presence of a DPOAE is determined by the level at which it exceeds the noise floor (Hall, 2000:137). This level is not standardized and varies from three to six dB (Lonsbury-Martin et al., 1991:971; Biologic Systems, 2002; Prieve, Gorga & Neely, 1991:381). For the purposes of this study the noise floor level was set at six dB to enhance test sensitivity and specificity (Biologic Systems, 2002). In addition DPOAEs allow for the selection of specific frequencies at which measurements can be made (Gorga et al., 1993:1494; Lonsbury-Martin & Martin, 1990:144).

Figure 4.9 specifies the prevalence of the distortion products in the test group for the screening DPOAE test. The graph differs to the previous prevalence graph in that the percentages of present DPOAEs are depicted at each frequency (geometric mean of f1 and f2). This allows the researcher to describe the characteristics of the distortion product.

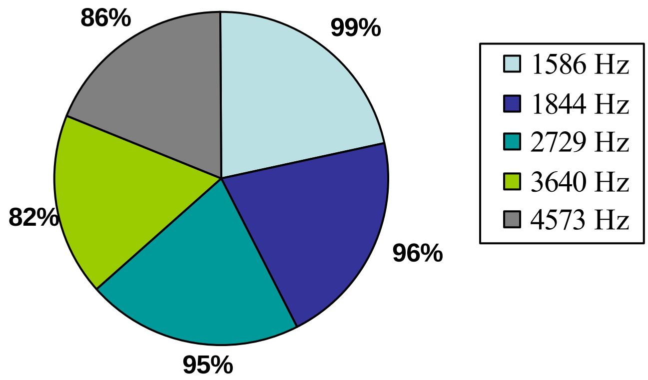

Figure 4.9: Prevalence of DPOAEs in the noise-exposed test group for screening DPOAE test

As the frequency increased so the prevalence of the DPOAEs decreased that is 99 percent prevalence was obtained at 1586 Hz as opposed to 86 percent prevalence at 4573 Hz. The results from both machines have been averaged to obtain the prevalence percentages depicted in **Figure 4.9**. Further analysis at the separate frequencies indicated that the lower DPOAE amplitudes were found at 4573 Hz. This is typical of the DP gram shape obtained with NIHL (Sliwinska – Kowalska, 1998:29; Tognola et al., 1999:243). **Figure 4.10** shows an example of this configuration.

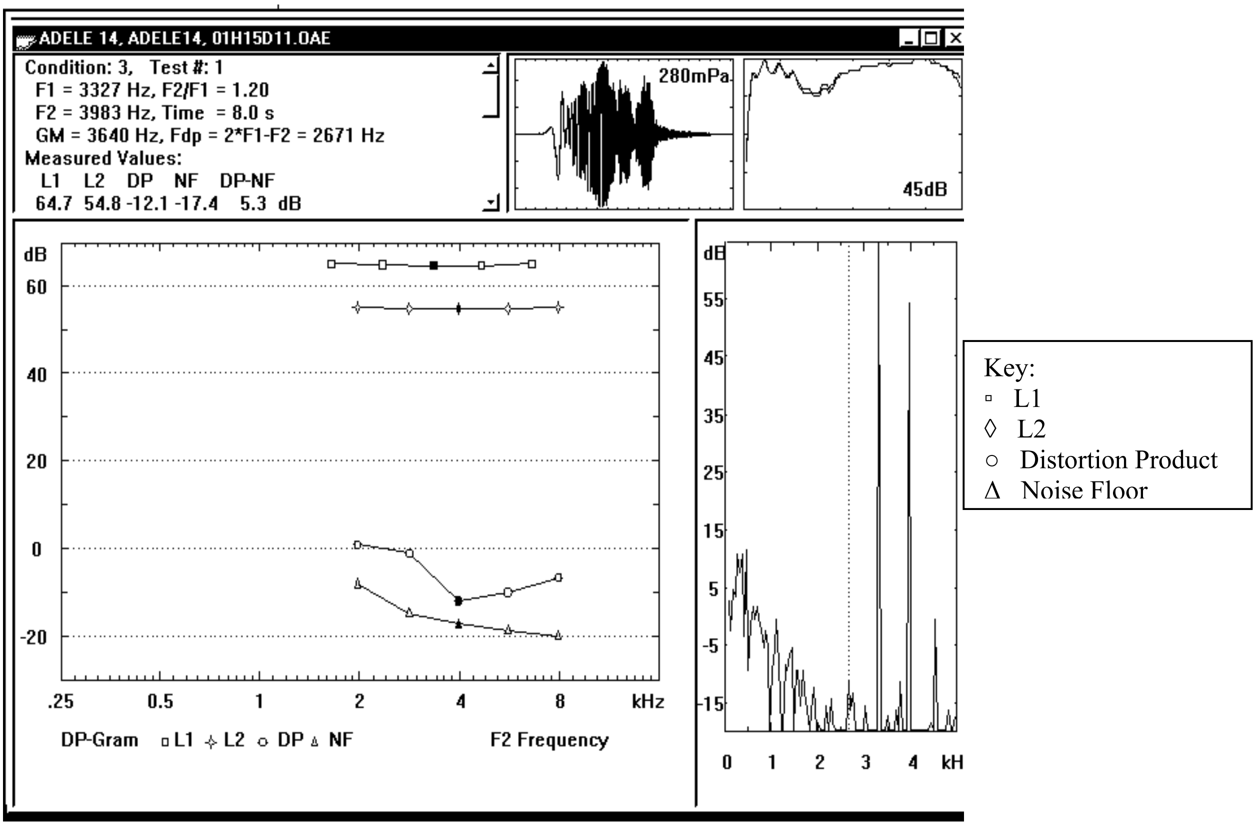

Figure 4.10: DPOAE diagnostic test tracing for a noise-exposed subject

Figure 4.10 indicates the tracing of a DP gram from one subject part of the noise-exposed group. Notching can be clearly seen in the highlighted region of 3640 Hz in the lower left block of the figure. The distortion product/noise floor ratio is 5.3 dB at this point indicating an absent DPOAE. The DPOAEs are however present at the preceding and subsequent frequencies. This can be compared to a normal tracing obtained as depicted in **Figure 4.11.**

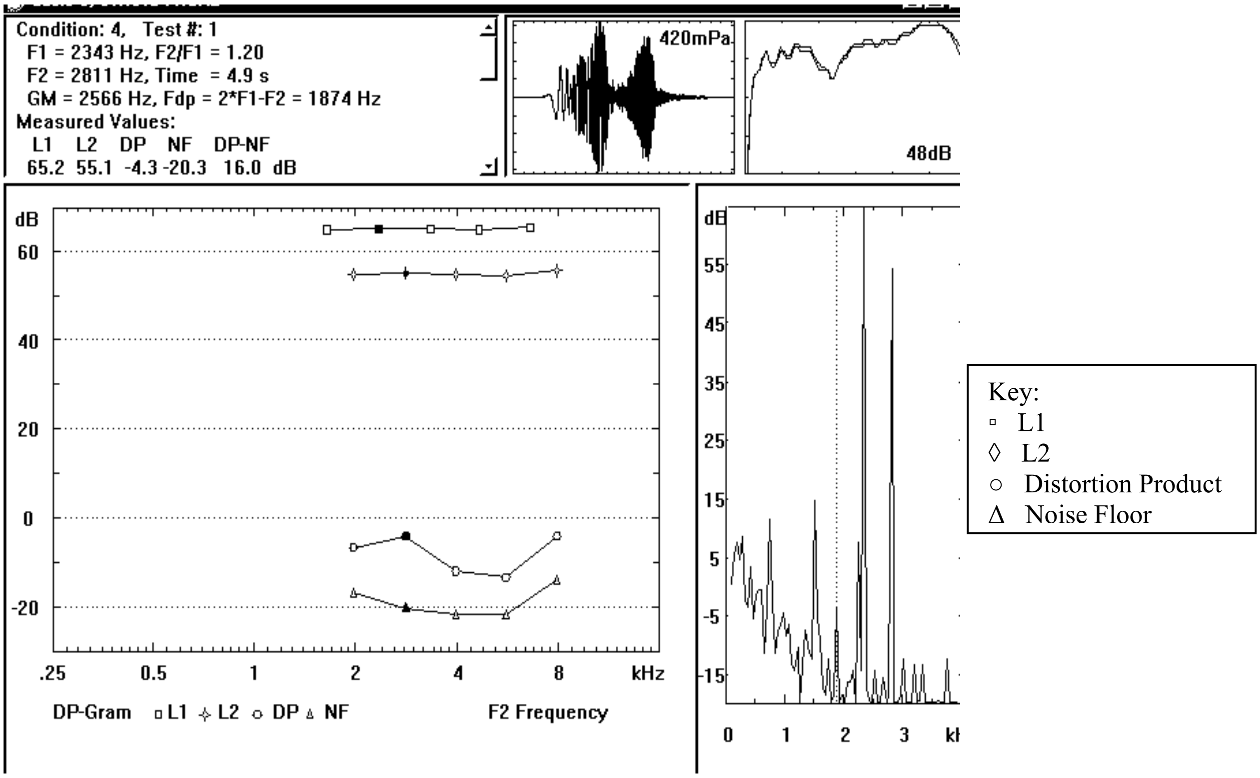

Figure 4.11: DPOAE diagnostic tracing for a normal non-exposed subject

Figure 4.11 indicates that all DPOAEs are present for the entire frequency range depicted. All the DPOAE measurements obtained on the graph are above the noise floor by at least six dB, indicating present DPOAEs. For example the highlighted region at 1874 Hz has a distortion product to noise floor (DP - NF) ratio of 16 dB. No notching is visible as in **Figure 4.10**.

Table 4.3 indicates the means of the DPOAE amplitudes as they were depicted on the DP grams.

Table 4.3: The means and standard deviations of the DPOAE amplitudes for the DPOAE screening test

Machine 1	Group	Frequency (geometric mean of f1 and f2)	Mean	Std deviation
Screening DPOAE test	Non-exposed group	2729 Hz	21 dB	6
		3640 Hz	24 dB	6
		4573 Hz	21 dB	7
	Noise-exposed group	2729 Hz	17 dB	6
		3640 Hz	17 dB	6.6
		4573 Hz	14 dB	6.8
Machine 2	**Group**	**Frequency (geometric mean of f1 and f2)**	**Mean**	**Std deviation**
Screening DPOAE test	Non-exposed group	2729 Hz	17.9 dB	6.6
		3640 Hz	15.89 dB	6
		4573 Hz	11 dB	6.72
	Noise-exposed group	2729 Hz	14.6 dB	5.67
		3640 Hz	11.96 dB	5
		4573 Hz	8.56 dB	5

As **Table 4.3** depicts, the means for the noise-exposed test group at 4573 Hz (14 and 8.56 respectively), were lower than that for the non-exposed normal group (21 and 11 respectively). Although a statistical significant difference was not obtained between the groups, the results do indicate that 4573 Hz was primarily affected as compared to the other frequencies. These differences were not sufficiently large to accurately differentiate between normal and abnormal ears. Similar results were observed as depicted in **Figure 4.12** and **Table 4.4** below.

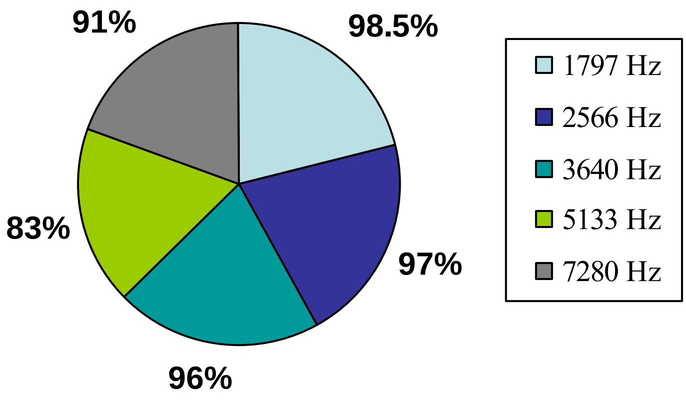

Figure 4.12: Prevalence of DPOAEs in the noise-exposed test group for diagnostic DPOAE test

In **Figure 4.12** the results for the DPOAE diagnostic test are depicted. The frequency range tested for the diagnostic DPOAE test is larger than for TEOAEs and includes five to eight KHz (Hall, 2000:136). **Figure 4.12** indicates the geometric mean of f1 and f2 values in Hertz. Similar to the results of the screening test, the prevalence decreased as the frequency increased. The prevalence in the region of 1797 Hz was 98, 5 percent and in the region of 7280 Hz, 91 percent. The prevalence differed between the machines. The overall prevalence for machine one was 93 percent and for machine two was 90 percent. These differences in prevalence found between the machines may be attributed to tester differences as has been discussed previously.

Table 4.4 indicates the means of the DP amplitudes as they were depicted on the DP grams for the diagnostic tests.

Table 4.4: The means and standard deviations of the DPOAE amplitudes for the DPOAE diagnostic tests

Machine 1	Group	Frequency (geometric mean of f1 and f2)	Mean	Std deviation
DPOAE Diagnostic test	Non-exposed group	3640 Hz	24.9 dB	5.9
		5133 Hz	17 dB	7.3
		7280 Hz	18 dB	7.45
	Noise-exposed group	3640 Hz	17.9 dB	6.7
		5133 Hz	13 dB	6
		7280 Hz	12.5 dB	6.6
Machine 2	Group	Frequency	Mean	Std deviation
DPOAE Diagnostic test	Non-exposed group	3640 Hz	17.6 dB	6
		5133 Hz	11 dB	6.9
		7280 Hz	12 dB	6
	Noise exposed group	3640 Hz	13 dB	5.8
		5133 Hz	8 dB	5.7
		7280 Hz	10.7 dB	5.4

In **Table 4.4** the mean value obtained at 5133 Hz was lower than those obtained at the other frequencies. This is similar to the findings for the DPOAE screening test. Although this trend was observed the results remained statistically insignificant with large standard deviations.

Thus the differences were overall statistically insignificant for both the screening and diagnostic DPOAE tests used as well as that found between the two machines. The differences obtained between the two machines may be attributed to the removal and replacement of the probe between each test by the different testers. The experience of each tester could also have played a part in the collection of the data.

A higher percentage of normal DPOAE tracings were however obtained for the normative group (97 percent with machine two and 99 percent with machine one for the screening tests) as compared to the test group (90 percent for machine one and 93 percent for machine two for the screening tests). The same trend was found to be true for the diagnostic DPOAE tests. The absent DPOAEs fell within the four to five KHz range. Researchers have shown that this range shows the greatest reduction in DP amplitude after noise exposure (Eddins et al., 1999:119; Martin, Lonsbury-Martin, Probst, Scheinin & Coats, 1987:192; Vinck et al., 1999:44). Vinck et al., (1999:47) found that DPOAE amplitudes were significantly reduced for geometric mean frequencies between 3,948 and 5,582Hz.

The absent DPOAE tracings at various frequencies for the non-exposed test group once again highlighted the fact that these ears may have been damaged previously by other factors as mentioned for TEOAEs or that the test procedure is too sensitive. However due to this finding the procedure used in the present study should be revisited so that more accurate differentiations may be made between normal and noise exposed ears, within this population group. As Hall (2000:491) indicates it is not useful to define hearing loss based on one or two test frequencies from an OAE test. Vinck et al., (1999: 52) suggested that DPOAEs may be more sensitive in detecting changes in the status of the cochlea than pure tone testing. Therefore DPOAEs may be useful in monitoring changes in cochlear status over time and this is important when dealing with the effects of NIHL. However within this population of mineworkers, due to few differences being found between the normal non-exposed group and that of the noise-exposed group, the feasibility of using DPOAEs as a screening tool is still questionable. This area of research regarding screening for NIHL with DPOAE test procedures requires further research.

4.6. The effect of age and years of noise exposure on the characteristics of the OAE results

The noise exposed test subjects' ages in the test group varied between 23 and 52 years, with the mean being 36,4 years and the standard deviation 6.7. The years of exposure ranged between one and 31 years with the mean being 11.5 years. In the non-exposed group the ages ranged from 18 to 35 years, the mean being 25.4 years and the standard deviation 3.9.

Subject age affects virtually any audiometric measure (Hall et al., 1994:36). Age effects have been reported for both types of OAEs (Baer & Hall, 1992:22). This has been attributed to cochlear use and the effect of exposure to noise throughout life and the onset of presbycusis (Baer & Hall, 1992:22). In particular DPOAEs decrease as a function of age for stimulus frequencies above two KHz. Based on these findings, a decrease in OAE amplitude as age increased was expected. Four variables were used in the statistical analysis to investigate whether a trend existed between OAE measurements, years of exposure and age. The variables used included the years of exposure, which machine was used, which group the subject was allocated to and age. **Table 4.5** and **4.6** indicate which variables affected the measurements. For both tests the tables indicate at separate frequencies which variable appeared to be the primary influence. The variables include the age of the subject, the length of noise exposure, and the group the subject was allocated to and whether machine one or two was a variable.

Table 4.5: Influence of four variables on the DPOAE measurements

Frequency in Hz(GM)	DPOAE diagnostic test	Frequency in Hz (GM)	DPOAE screening test
1719	Age	1844	Group
2566	Age	2729	Age
3640	Age	3640	Age and machine
5133	Age	4573	Age and machine
7280	Age	(frequency not tested)	(frequency not tested)
Overall influence	**Age**	**Overall influence**	**Age**

Table 4.6: Influence of four variables on the TEOAE measurements

Frequency in KHz	TEOAE diagnostic test	TEOAE screening test
2	Age	Age and length of exposure
3	Group and machine	Group
4	Group and length of exposure	Machine and age
Overall influence	**Group**	**Age and machine**

Logistic regression procedure (Howell, 1995:166) indicated that age was the primary influence or predictor for the OAE result in this study. The trend which was evident indicated that the older the subject, the more probability there was in obtaining an abnormal OAE result. This was predominantly evident on the DPOAE diagnostic and screening tests and the TEOAE screening test. Similar results were expected for the number of years of exposure but this was not observed. The age of the subject did not have any significant correlation with the variable of length of exposure to noise. A number of subjects were younger than others but had been exposed to noise for a longer period of time. Research has indicated that as age increases, so the amplitude of the OAE decreases in normal ears (Bonfils et al., 1988 cited in Baer & Hall, 1992:22). With DPOAEs it has been shown that the DPOAE decreased as a function of age for frequencies above two KHz (Lonsbury-Martin, Cutler & Martin, 1991 cited in Baer & Hall, 1992:22). However the decrease in the OAE reaction correlates highly with the general decrease in hearing sensitivity associated with aging (Baer & Hall, 1992:22). On the other hand, Hall (2000:165) states that advancing age does not tend to have a significant influence on OAE amplitudes in persons with normal hearing acuity. The decrease in OAE amplitude may be due to other influences such as changes in middle ear function or presbycusis.

Age was a primary predictor of absent TEOAEs at two KHz more so than at three or four KHz in the TEOAE diagnostic test. This holds true with other reports in the literature (Kowalska & Sulkowski, 1997:456). The OAE result on the TEOAE diagnostic test was primarily influenced by the variable of group i.e. the test versus the normative group. The trend here indicated that there was a greater probability of obtaining a normal reading from subjects in the normal group than in the test group. However, overall, age appeared to be the primary indicator for expecting a reduction in the prevalence of OAE values due to noise exposure.

No trend could be established regarding the number of years of exposure to noise. However it was expected that the more years of exposure to noise; the more the OAE amplitude would decrease. Kowalska and Sulkowski (1997:456) found that the decrease in OAE amplitude and reproducibility was related more to the duration of noise exposure than to the age of the subjects. However the subjects taking part in this 1997 study all had some degree of NIHL. The fact that the duration of noise exposure and its lack of effect on the OAE measurements in this study, could possibly be linked to the individual susceptibility for NIHL of the test subjects, or to effective noise conservation methods. This could especially be true since this group showed normal hearing thresholds in the presence of more than one year's exposure to high levels of noise.

In a few of the test subjects with many years of noise exposure, normal OAE tracings were still observed. Though it must be kept in mind that the results were statistically insignificant, Franklin, Lonsbury-Martin, Stagner and Martin (1991), cited in Probst et al., (1991:2060) found similar results with experiments on rabbits. Susceptibility to the effects of repeated noise exposure on DPOAE amplitude was discovered. Therefore it is possible that workers exposed to noise may become less susceptible to noise damage over time. DPOAEs may also therefore be a valuable tool in monitoring and predicting susceptibility to noise exposure.

With regard to TEOAEs, Kowalska and Sulkowski (1997:442) reported that the decline in amplitude and reproducibility values in TEOAE testing was more related to length of exposure than aging effects. However it is further reported that insufficient data exists on TEOAEs in ears with prolonged exposure to noise. For the clinical value of OAEs in industry to be thoroughly evaluated with regard to age and length of exposure to noise, it is recommended that longer term studies should be done. This is due to contrary reports in the literature highlighting the fact that length of exposure is a better predictor of NIHL than is age (Kowalska & Sulkowski, 1997:442).

In conclusion therefore, a trend was established with regard to age and OAE measurements as compared to the other variables used. The older the subject, the more adversely the OAE measurement was affected. Within this population group of mineworkers then, it may be predicted that the older the worker is, the more likely he will have cochlear damage. The results indicate that the worker’s length of exposure to noise can not be used as a predictor for cochlear damage.

4.7. Inter-test reliability

The measurement of OAEs can be influenced by a number of factors. These include environmental conditions, the calibration of the machine or in this case, machines (referred here as machine one and machine two), and tester factors. The machines did not agree in terms of the results obtained. Poor inter-test reliability was obtained. This trend was particularly evident in the frequency regions above two KHz which are important in the differential diagnosis of cochlear damage and other causes. The primary differences were especially evident with the TEOAE tests. **Table 4.7** describes the correlation in terms of the p value where a good correlation is indicated by p>0.05; and a poor correlation or a large difference between the machines by p<=0.05 (Howell, 1995:104)

Table 4.7: Inter-test agreement between machine one and two

Frequency in Hz (GM)	DPOAE diagnostic test	Frequency in Hz (GM)	DPOAE screening test	Frequency in KHz	TEOAE diagnostic test	TEOAE screening test
1797	0.6856	1844	0.4697	1	(not applicable)	(not applicable)
2566	0.62	2729	0.218	2	0.156	0.46
3640	0.34	3640	0.045	3	0.000000000005	0.0000000000094
5133	0.0002	4573	0.0000639	4	0.0000038	0.0000000042
7280	0.218	(frequency not tested)	(frequency not tested)	5	(frequency not tested)	(frequency not tested)

The agreement between the machines was, combining both test and normative groups of subjects, indicated by p values, and obtained with Fisher's Exact test (Howell, 1995:305).

As the table indicates poor correlations were obtained between the machines for the TEOAE tests and the DPOAE screening test. This poor agreement was especially evident at the frequencies important for differentiating between normal and abnormal ears i.e. three KHz to five KHz range. Due to the fact that the test procedures and test parameters did not differ between the machines and that the tests run automatically, the poor agreement may be attributed to extraneous factors such as environment and tester differences. These factors thus affected the sensitivity and specificity of the outcome of the results.

Further analysis revealed that machine two obtained a greater percentage of abnormal readings than did machine one. The greatest differences are evident with the TEOAE tests. **Figure 4.13** indicates the percentage of overall normal and abnormal readings obtained per TEOAE test. These percentages are a combination of all the measurements at all the frequencies tested and not based on percentage reproducibility at separate frequencies.

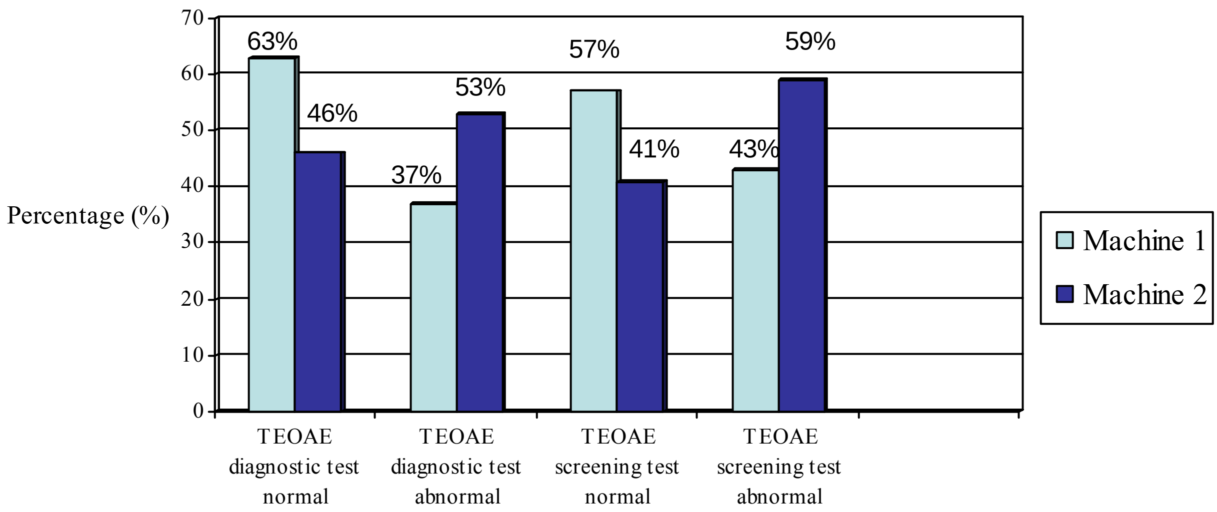

Figure 4.13: Percentage of normal and abnormal readings for the TEOAE tests

Figure 4.13 indicates the percentage of normal and abnormal readings obtained for the TEOAE tests for both groups of subjects. A higher number of normal results were obtained with machine one as opposed to machine two for the TEOAE screening tests. The same pattern was observed for the diagnostic test. Figure 4.13 indicates for example that 57 percent of normal readings was obtained with machine one as compared to 41 percent of normal readings from machine two with the TEOAE screening test, for both groups. It is possible that machine one was less sensitive than machine two in detecting abnormal OAEs and therefore resulting in less false positives. The extraneous tester variable could also have had an effect on the differences in these results. The effect of this variable is discussed below.

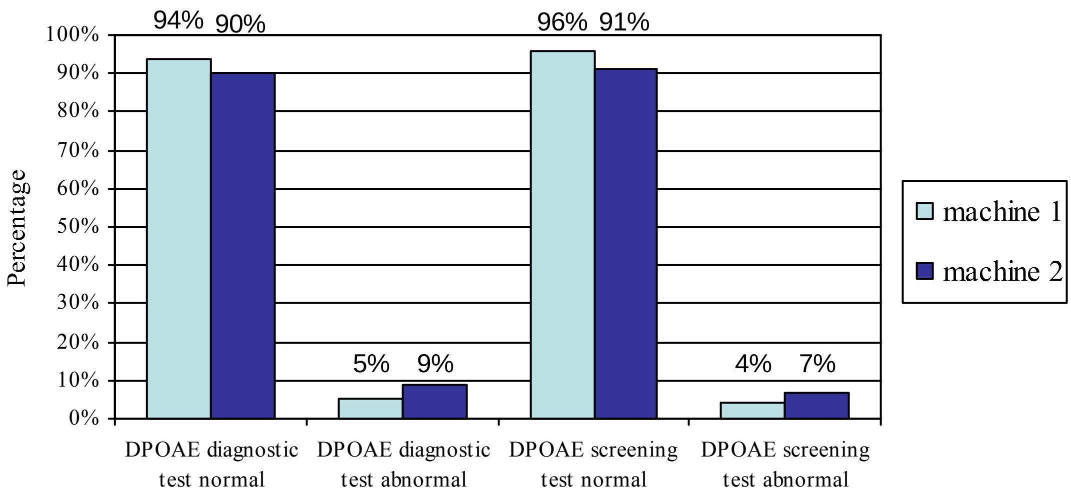

Figure 4.14: Percentage of normal and abnormal readings for the DPOAE tests for all subjects

In **Figure 4.14** machine one had a greater number of passes than did machine two. For example machine one obtained a 94 percent pass rate as compared to that of a 90 percent pass rate with machine two on the DPOAE diagnostic test. Machine one obtained a pass rate closer to the 96 percent reported in the literature than did machine two. Therefore the results obtained with machine one indicated less false positives and thus was perhaps more applicable in its level of sensitivity and specificity. Thus the same trend was observed as for the TEOAE tests. The discrepancy between the two machines was however greater with the TEOAE tests than the DPOAE tests.

This outcome was not anticipated. It was expected that no differences would exist in the readings obtained between the machines, i.e. a good inter-test reliability, would be observed, primarily because of the nature of the tests and testing procedures. The tests ran automatically and the machines did not differ in terms of the protocols used. The only areas of difference were with regard to the testers, and the calibration of the equipment. The calibration of the equipment has reportedly minimal effect on the OAE results (Biologic Systems, 2002). However tester variables can influence results. As has been discussed previously, two Audiologists undertook to complete the testing. Each audiologist was assigned to a machine and each had had different levels of experience and exposure in performing the tests. These differences in experience could have had an effect on correct probe placement in the subjects' ears, and evaluation of noise levels during testing. References in the literature to using different testers are minimal and in those studies which did utilize different testers, such discrepancies were not obtained (Prieve et al., 1991:3308). Therefore further investigation needs to be considered as possibly affecting the inter-test reliability. Factors which could be considered in future inter-test reliability measures are numerous. Extrinsic factors such as environmental noise and tester differences are known to influence OAE test results. An understanding of these is important for making a conclusion regarding whether changes are attributable to these or to cochlear factors (Harris, Probst & Wenger, 1991:140). Measurement differences can be a result of changes in instrumentation, and test environment. In this study these factors were not sufficiently controlled. Both OAE systems had only been calibrated before purchase and not before the test phase of the study. Reasons for this are discussed below. The probe fit did not remain stable between testing and was removed and reinserted. These factors can lead to variability in the test results which is clearly unwanted (Prieve et al., 1991:383). OAE responses within individuals are known to be stable over time (Harris et al., 1991:136). Therefore the differences in the results may purely stem from inter-test and inter-tester differences.

Reliability can be defined as the "extent to which a test yields consistent scores on repeated measures" (Stach, 1997:176, cited in Hall, 2000:127). According to Hall (2000:488) there are no formal studies addressing DPOAE reliability especially when it comes to testing outside of laboratory conditions. TEOAEs on the other hand, have been shown to have excellent reliability, more so at one to three KHz than at four KHz (Hall, 2000:127). The poor inter-test reliability in this study occurred primarily with the TEOAE tests. Possible reasons for this having occurred include tester variability, probe fit and environmental factors. Artifacts can be created by improper probe fit in the ear canal which resembles OAEs (Prieve et al., 1991:383). Prieve et al (1991:3308) used two measurement systems to rule out the presence of artifacts masquerading as OAEs in a single profoundly hearing impaired subject. Although the two machines differed in terms of probe type i.e. a custom designed system versus the commercially available ILO 88 (Otodynamics, Ltd), the researchers found the results of the two machines very similar. Another variable which may have had an effect on the results is that of calibration. Before the year 2000 no international standard for the calibration of OAE equipment existed (de Klerk, 2000). Since then all OAE equipment can be calibrated. During the test phase of this study, neither machine had been calibrated after its purchase. One of the machines had been in use for more than two years and the other was relatively new. Hall (2000:358) indicates that calibration is a necessary process as the OAE machine's microphone sensitivity has an impact when calibrating the sound stimulus levels in the subject's ear before the test commences. If the calibration of the equipment is incorrect, the measurement of the noise levels and stimulus in the subject's ear will therefore also be incorrect. Therefore a poor reading may be obtained. Thus calibration aspects could have influenced these results. According to Biologic Systems (2002) the calibration variable should have minimal effect, however, with regard to this study it should not be ruled out. The experience of the testers was an additional variable influencing the results. Therefore inter-tester reliability becomes questionable. One audiologist had only recently begun using OAEs in her practice, with no previous university training in the use and application of OAEs. The second audiologist had been testing for a number of years and had had training both at university and at a tertiary level in the use and application of OAEs. This difference in experience could have influenced the probe fittings with regard to insertion angles and overall testing ability. These factors are however difficult to measure and these are tentative, subjective conclusions. This however has implications within the industrial sector regarding who ultimately performs the testing as there are numerous personnel with differing levels of expertise involved in audiometric testing on the mines. These include nurses, audiometrists, audiologists or hearing aid acousticians who are registered with the Health Professions Council of South Africa or who have a certificate in audiometry recognized by the Department of Mines and Energy (DME) (SANS, 2004:27). Further research is therefore required to address these issues before OAE testing can be applied as a single procedure to detect NIHL in industry.

4.8. The sensitivity and specificity of Transient OAEs for the early detection of NIHL

Hotz et al., (1993: 478) and Vinck et al., (1999:50) concluded that TEOAE testing, for the purposes of detecting cochlear changes in noise exposed subjects, was more sensitive than pure tone audiometry. In the present study, however, the reproducibility and amplitude reductions obtained in both groups indicated that the sensitivity of the TEOAE tests appeared to be too high for the purposes of detecting cochlear changes. This study used 70 percent to indicate a pass in an attempt to increase the sensitivity of the test to early noise damage. However this may have been too high for this population group. Both subjects from the non-exposed and noise exposed groups exhibited absent OAEs at four KHz. With these results the use of TEOAEs as a large scale screening tool in the adult population, may therefore result in a large number of false positives and thus unnecessary referrals for diagnostic testing. The tests were specific in that the greatest amount of damage was indicated as occurring at four KHz. This is the region where noise damage is first seen. Thus the results from the TEOAE tests indicated that sensitivity was too high and repeatability poor. Once again the parameters and values used may have to be reconsidered with this population to make screening with TEOAEs a viable method. Although the settings for each test were based on previous research findings, the collection of a database of normative data within this population group would have provided additional guidance with regard to the use of more appropriate settings.

A poor inter-tester reliability was obtained with $p>0.05$ at only one of the four test frequencies. The poor inter-tester reliability adversely affected these results and thus at present it is not a reliable method to use in isolation in the industrial setting. However with further investigation TEOAE testing may become part of the test battery used in hearing conservation programs. Utilizing a number of audiometric tests or test battery aids the investigator in making accurate decisions regarding the nature and extent of the hearing loss and thereby implementing appropriate management. This is known as the cross-check principle in audiology. TEOAEs utilized within a test battery, would therefore provide the audiologist with additional information to verify and confirm other audiometric test results.

4.9. The sensitivity and specificity of Distortion Product OAEs for the early detection of NIHL

Sutton et al., (1994:161) and Vinck et al., (1999:44) indicated that DPOAEs could be used as a more sensitive measure for noise damage as compared to that of pure tone audiometry. The DPOAE tests were less sensitive than the TEOAE tests, in that a lower percentage of the non-exposed group was identified as having absent DPOAEs in the presence of normal hearing acuity. DPOAE tests appeared to be more specific in detecting noise damage in the frequency regions where damage was expected to occur. For four percent of the subjects in the noise-exposed group, diagnostic DPOAE test, and five percent for the screening DPOAE test, notching was observed within the three KHz region. The DP dropped to below six dB above the noise floor. This indicated an absent DPOAE within this frequency region. In the presence of normal pure tone thresholds, this indicated possible early damage to the cochlea. This frequency specificity is one of the advantages of using DPOAEs. Thus fewer false positives may be obtained with DPOAEs as compared to using TEOAE tests. The differences obtained between the two machines were statistically insignificant with the DPOAE tests. However the correlation obtained between the two machines was good for the DPOAE diagnostic test ($p>0.05$ at four out of five of the test frequencies). A poorer correlation was found for the DPOAE screening test ($p>0.05$ at two out of four test frequencies). These correlations can be viewed in Table 4.7. The analysis of the DPOAE tests indicated a higher repeatability than for the TEOAE tests and a higher sensitivity to presymptomatic cochlear damage.

4.10. Conclusion

The results from the OAE testing indicated that as the stimulus frequency is increased, the amplitude of the emission decreased. The primary frequency region to be affected was in the region of four KHz. Although this was evident for both groups, the noise exposed group had the greatest prevalence of absent OAEs at this frequency. The fact that the normative group exhibited absent OAEs, higher than that reported in the literature, indicated that the parameters used for the TEOAE tests for this population may have been too sensitive and therefore not sufficiently specific. With the diagnostic DPOAE testing the greatest variation occurred at four and five KHz. Here the noise exposed test group exhibited the greatest percentage of absent DPs at these frequencies. A pass rate of at least 98 percent was not obtained for the normative non-exposed group which was unexpected as DPOAEs are present in almost all normal hearing ears (Gorga, Neely, Bergman, Beauchaine, Kaminski & Liu, 1994:1500). The inter-tester reliability for the DPOAE tests was better than for the TEOAE tests. Machine two showed a higher percentage (seven to nine percent) of absent DPOAEs than did machine one (four to five percent). Machine one indicated a smaller difference existing between the two groups and more normal responses (94 to 96 percent) were obtained. This indicates that machine two may have had a lower sensitivity and specificity than machine one. The DPOAE screening test indicated similar results for both groups, with absent DPs being found primarily in the four KHz region. Once again machine two had a lower pass rate (91 percent) than did machine one (96 percent). The DPOAE screening test showed a 100 percent pass rate for the normative group. This pass rate was anticipated as according to the reports in the literature (Hall, 2000:15). A larger sample would be necessary for both groups in order to evaluate statistical significance.

The results regarding inter-test reliability differed more significantly with the TEOAE tests as with the DPOAE tests. This poor inter-test reliability may be attributed to environmental and inherent tester factors.

Further sub-aims included the effect of age and length of exposure to noise on the OAE tracings. Age was the primary predictor for changes in OAEs. No such trend was established with regard to the years of exposure.

In conclusion therefore, a normative sample is vital to ensure that the sensitivity and specificity of both the TEOAE and DPOAE tests are accurate for the purposes of a hearing screening program in industry (Hall, 2000:126). Although the region of three to four KHz has been used to differentiate between normal and abnormal ears, other frequency regions may be more applicable with this population group due to the low prevalence of tracings at three to four KHz in the normative sample

The results support the findings of Hall (2000: 490) in that OAE testing seems to have potential as a screening test in that it has proved to be extremely sensitive in the diagnosis of pre-symptomatic cochlear damage, but may be too sensitive for practical benefits to be obtained from wide-spread application in screening programs. OAE tests may however prove to be valuable within an audiometric test battery.

Chapter 5: Conclusion

This chapter discusses the main conclusions derived from the research as well as the limitations of the study and future research that is indicated.

The main aim of this study was to evaluate OAE testing as a means for early identification of noise-induced hearing loss in South African mine workers. The results support the findings of Hall (2000:490) in that OAE testing proved extremely sensitive in the diagnosis of pre-symptomatic cochlear damage, but too sensitive for practical benefits to be obtained from wide-spread application in screening programs.

TEOAEs are reportedly present in at least 95 percent of audiometrically normal ears (Lucertini et al., 1996:86; Bonfils et al., 1988:27). Although both groups had normal audiometric hearing thresholds, the prevalence of TEOAEs was low for the normal non-exposed group for the screening test (five percent for machine two and 35 percent for machine one) as well as for the diagnostic TEOAE test (50 percent obtained for machine one and 24 percent for machine two). The prevalence of TEOAEs was generally lower for the noise-exposed test group when compared to that of the normal non-exposed group. Here 11.5 percent prevalence was obtained for the TEOAE screening test and 15 percent prevalence for the diagnostic TEOAE test. This prevalence is based on the pass rate obtained at four KHz. The absent TEOAEs were by and large observed to be within the four KHz region. This was indicated by the amplitude and reproducibility scores of the transient echoes. Hall (2000:484) reported that "the relatively greater sensitivity of OAEs to cochlear dysfunction is exemplified clinically by reports of abnormal or absent OAEs among patients with normal audiograms". The variance was however large and the differences between the groups were statistically insignificant. However the low prevalence obtained for the normal non-exposed group is significant. The fact that the normative group exhibited absent OAEs where it was unexpected, indicated that the parameters used for the TEOAE tests for this population may have been too sensitive and therefore not sufficiently specific.

The prevalence obtained for the DPOAE tests was higher than that of the TEOAE tests. The normative non-exposed group obtained a higher prevalence (97 percent for machine one and 93 percent for machine two) than the noise-exposed group (93 percent for machine one and 90 percent for machine two). At least 96 percent prevalence was expected for both groups in the presence of normal audiometric hearing levels as reported in the literature (Gorga et al., 1994:1500). The inter-test reliability for the DPOAE tests was poor but higher than that of the TEOAE tests and therefore the data from each machine was interpreted separately. Overall machine two showed a higher percentage of absent DPOAEs than did machine one. Machine one indicated a smaller difference existing between the normative and noise exposed groups and more normal responses were obtained. This indicates that machine two may have had a lower sensitivity and specificity than machine one. With the diagnostic DPOAE testing the greatest variation occurred at four KHz and five KHz. Here the test group exhibited the greatest percentage of absent DPs at these frequencies. The DPOAE screening test indicated similar results with absent DPs being found primarily in the four KHz region. Once again machine two had a lower pass rate than did machine one for the screening test. The results were overall statistically insignificant. A larger sample would be necessary for both groups in order to evaluate statistical significance. However DPOAEs showed the more promise than TEOAEs for incorporation into a hearing screening program based on the prevalence measurements obtained.

Age was the primary predictor for changes in OAEs. The older the subject the more likely it was that lower or absent OAEs were obtained. According to Hall (2000:175) age itself does not influence TEOAEs or DPOAEs in any overt way. Rather other factors such as length of exposure to noise may have an effect and should be considered. However in this study the length of exposure did not have any effect on the outcome of the OAE testing. In the present study, age was found to be the best predictor of diminished OAE tracings. The older the subject the more likely that poor OAE results would be obtained. The most significant decrease in the OAE tracings was observed from approximately 38 to 40 years and onwards (Clark, de Koker, Franz & Mackay, 2002:33).

The poor inter-test reliability seen in this study highlights the importance of environmental and tester factors as well as equipment issues. The aim of screening with OAEs within the industrial sector and more particularly in the mining sector is to be able to test outside laboratory conditions and still obtain reliable results. Thus these factors, environmental and tester are important considerations in the implementation of screening procedures with OAEs. The environment needs to be carefully monitored with regards to noise levels. Extraneous noise needs to be eliminated as far as possible and the control of subject noise is additionally vital. As with all audiometric equipment, the OAE machine needs to be regularly calibrated and checked. The tester completing the testing needs to be well trained and have a working understanding of cochlear dynamics and interpretation of results. This has implications for counseling of the subject and subsequent appropriate referrals. It is thus concluded that a qualified audiologist should complete the testing. An audiologist is qualified in all these areas of noise control, counseling, OAE testing and interpretation (Health Professions Council of South Africa, 2004). The poor inter-tester results also indicate that the audiologist should possibly receive additional training in the use of OAEs.

An understanding of how extrinsic factors can influence TEOAEs is important for obtaining valid results. This aids in the tester being able to determine whether changes are attributable to cochlear damage or other factors such as presbycutic hearing loss. As Hall (2000:135) states, "differences in probes" or probe fittings "probably account for much of the variation in DPOAE findings among devices, and from one study to the next". When factors such as these are better controlled, changes can be attributable to cochlear factors and not others. The test parameters used also need to be reevaluated and possibly different protocols used to find the best one suited to this population group.

The limitations of this study had an effect on the sensitivity and specificity outcomes of both the DPOAE and TEOAE testing. One limitation was the lower than expected prevalence of TEOAEs and DPOAEs in the normative sample. This indicated that a normative database would be invaluable for making correct decisions regarding OAE tracings obtained in this population group (Hall, 2000:132). This would ultimately decrease the number of false positives and thus the referral rate would be controlled. Though more abnormal responses were obtained from the test group, simply the presence of a TEOAE response may not be sufficient in differentiating between normal and damaged ears due to the variety of responses obtained (Lucertini et al., 1996:79). Thus it is proposed that OAEs could be used if a test-retest reliability is established for the protocol, testers, equipment and the population being tested (Miller & Marshall, 2001:1). With obtaining a normative sample the test parameters could be refined for use in this population group, as was the case with the TEOAE tests being too sensitive. Lonsbury-Martin et al., (1994:173) used a larger than 50 percent reproducibility for a pass rather than 70 percent and a larger than zero dB signal to noise ratio for the subset of frequency bands rather than the entire range. These parameters could be an option in future research.

Further limitations of the study stemmed from the testing environment. This environment was less than ideal and extrinsic factors such as environmental noise were not adequately controlled to ensure reasonable outcomes. However this is possibly the test environment that will be available at any given industry. Therefore the feasibility of OAE testing on a large scale is questionable. Limited time was available and therefore retesting for confirmation of findings on the same machine was not completed. Tester factors as discussed previously were also a limitation and affected the sensitivity and specificity of the OAE outcomes.

This study indicated that further research is required before OAE screening can be implemented within the mining industry. A normative database would prove to be invaluable with the use of different criteria and values within the test protocols. The inter-test reliability should be repeated on a larger sample for valid conclusions to be made. Continued research is required into testing outside of laboratory conditions and the involvement of other affiliated personnel taking part in the testing procedures (ACOEM, 2002:3).

The results of this study thus indicated that further research is required before OAE testing can be implemented within the industrial sector in South Africa. At present it appears that it is not a replacement for conventional audiometry but may supplement it and form part of the diagnostic audiometric test battery within a hearing conservation program (Probst & Harris, 1993:860). At present prevention of NIHL continues to be the only effective method of intervention and all results, present and previous, continue to highlight the benefits of proactively identifying and diagnosing NIHL at the earliest possible stage.

References

Abrahamson, M. 1983. *Social Research Methods.* Englewood Cliffs: Prentice Hall Inc.

American College of Occupational and Environmental Medicine (ACOEM). 2002. Internet: http:// www.acoem.org. Access: 13 August 2004.

Arnold, D.J., Lonsbury-Martin, B.L. & Martin, G.K. 1999. High frequency hearing influences lower frequency DPOAEs. *Archives of Otolaryngology-Head and Neck Surgery.*, 125:215-222.

Atherley, G. & Johnston, N. 1981. Occupational noise and hearing conservation Selected issues. Internet: http://www.cdc.gov. Access: 10 May 2004.

Attias, J. & Bresloff, I. 1996. Noise-induced temporary otoacoustic emission shifts. *Journal of Basic & Clinical Physiology & Pharmacology.*, 7:221-233.

Attias, J., Bresloff, I., Reshef, I., Horowitz, G. & Furman, V. 1998. Evaluating noise-induced hearing loss with distortion product otoacoustic emissions. *British Journal of Audiology.*, 32:39-46.

Attias, J., Furst, M., Furman, V., Reshef, I., Horowitz, G. & Breslof, I. 1995. Noise-induced otoacoustic emission loss with or without hearing loss. *Ear and Hearing.*, 16:612-618.

Avan, P., Elbez, M. & Bonfils, P. 1997. Click-evoked otoacoustic emissions and the influence of high-frequency hearing losses in humans. *Journal of the Acoustical Society of America.*, 101:2771-2777.

Baer, J.E. & Hall, J.W. III. 1992. Effects of nonpathologic factors on otoacoustic emissions. *The Hearing Journal.*, 45 (11): 17-23.

Bicciolo, G., Ruscito, P., Rizzo, S. & Frenguelli, A. 1993. Evoked otoacoustic emissions in noise-induced hearing loss. *Acta Otorhinolaryngol.*, 13(6): 505-15.

Biologic Systems. 2002. Contact with W. de Klerk, South African agent.

Bonfils, P., Piron, J.P., Uziel, A. & Pujol, R. 1988. A correlative study of evoked otoacoustic emission properties and audiometric thresholds. *Archives of Otorhinolaryngology.,* 245:53-56.

Bonfils, P., Bertrand, Y. & Uziel, A. 1988. Evoked oto-acoustic emissions: Normative data and presbycusis. *Audiology.*, 27:27-35.

Bonfils, P. & Uziel, A. 1989. Clinical applications of evoked acoustic emissions: Results in normally hearing and hearing-impaired subjects. *Annals of Otology, Rhinology and Laryngology.,* 98:326-331

Brownell, W. E. 1990. Outer hair cell electromotility and otoacoustic emissions. *Ear and Hearing.,* 11(2):82-92.

Clark, A., de Koker, E., Franz, M. & Mackay, G. 2002. Feasibility of using otoacoustic emission methods for screening early hearing impairment in South African mineworkers. Final report for the Safety in Mines Research Advisory Committee on Health 802.

Clark, W.W. & Bohne, B.A. 1999. Effects of noise on hearing. MsJAMA online, 281:1658-1659. Internet: http://www.ama-assn.org. Access: 3 June 2004

Collet, L., Gartner, M., Moulin, A., Kauffman, L., Disant, F. & Morgan, A. 1989. Evoked otoacoustic emissions and sensorineural hearing loss. *Archives of Otolaryngology- Head and Neck Surgery.*, 114:1060-1062.

Collet, L., Veuillet, E., Chanal, J. M. & Morgan, A. 1991. Evoked otoacoustic emissions: Correlates between spectrum analysis and audiogram. *Audiology.,* 30:164-172.

Daniell, W.E., Swan, S.S., McDaniel, M.M., Stebbins, J.G., Seixas, N.S. & Morgan, M.S. 2002. Noise exposure and hearing conservation practices in an industry with high incidence of workers' compensation claims for hearing loss. American Journal Ind Med., 42(4):309-317. Internet: http://www.ncbi.gov. Access: 10 May 2004.

Davis, H. & Silverman, S. R. 1996. *Hearing and Deafnes*. New York: Holt, Rinehart and Winston.

De Klerk, W. 2000. Biologic Systems agent. Personal contact. Johannesburg: RSA.

De Koker, E. 2001. Personal contact.

Department of Minerals and Energy Noise Control in Mines. 1997. *Guideline document No.: ZMR922UU; noise control in mines*. Western Australia: P 39, Version 1.0

Doke, L. 1996. Hearing loss in the workplace: now employers will have to listen. *Safety Management.,* August: 24-26.

Durrant, J.D. 1992. Distortion product OAE analysis: is it ready for broad clinical use? *The Hearing Journal.,* 45(11):42-46.

Eddins, A.C., Zuskov, M. & Salvi, R.J. 1999. Changes in distortion product otoacoustic emissions during prolonged noise exposure. *Hearing Research.,* 127:119-128.

Engdahl, B. 1996. Effects of noise and exercise on distortion product otoacoustic emissions. *Hearing Research*., 93:72-82.

Engdahl, B., Arneson, A. R. & Mair, I. W. S. 1994. Reproducibility and short-term variability of transient evoked otoacoustic emissions. *Scandinavian Audiology.,* 23:99-104.

Engdahl, B. & Kemp, D.T. 1996. The effects of noise exposure on the details of distortion product otoacoustic emissions in humans. *Journal of the Acoustical Society of America., 99:1573*-1587.

Engdahl, B., Woxen, O., Arneson, A. R. & Mair, I. W. S. 1996. Transient evoked otoacoustic emissions as screening for hearing losses at the school for military training. *Scandinavian Audiology.,* 25:71-78.

Engdahl, B. & Tambs, K. 2002. Otoacoustic emissions in the general adult population of Nord-Trondelag, Norway: II. Effects of noise, head injuries and ear infections. *International Journal of Audiology.,* 41(1):78-87.

Fabiani, M. 1993. Evoked otoacoustic emissions in the study of adult sensorineural hearing loss. *British Journal of Audiology.,* 27:131-137.

Ferguson, M.A., Smith, P.A., Davis, A.C. & Lutman, M.E. 2000. Transient-evoked otoacoustic emissions in a representative population sample aged 18 to 25 years. *Audiology.,* 39(3): 125-134.

Gaskill, S. & Brown, A. 1993. Comparing the level of the acoustic distortion product 2f1-f2 with behavioral threshold audiograms from normal-hearing and hearing-impaired ears. *British Journal of Audiology.,* 27:397-407.

Giebel, A. & Redemann, E. 1992. Screening infants and children by means of TEOAEs. *The Hearing Journal.,* 45:25-28.

Gorga, M. P., Neely, S. T., Bergman, B., Beauchaine, K., Kaminski, J. R., Peters, J. & Jesteadt, W. 1993. Otoacoustic emissions from normal-hearing and hearing-impaired subjects: Distortion product responses. *Journal of the Acoustical Society of America.,* 93:2050-2060.

Gorga, M.P., Neely, S.T., Bergman, B.M., Beauchaine, K.L., Kaminski, J.R. & Liu, Z. 1994. Towards understanding the limits of distortion product otoacoustic emission measurements. *J. Acoust Soc Am.,* 96(3):1494-1500.

Gorga, M., Neely, S., Ohlrich, B., Hoover, B., Redner, J. & Peters, J. 1997. From laboratory to clinic: A large-scale study of distortion product otoacoustic emissions in ears with normal hearing and ears with hearing loss. *Ear and Hearing.,* 18: 440-455.

Guild, R., Ehrlich, R. I., Johnston, J.R. & Ross, M. 2001. *A Handbook on Occupational Health Practice in the South African Mining Industry.* Johannesburg: SIMRAC.

Guy, R., Arafat, I., Edgley, C & Allen, D. 1987. *Social Research Methods.* Boston: Allen & Bacon.

Hall, J.W. III. 2000. *Handbook of Otoacoustic Emissions.* California: Singular Publishing.

Hall, J.W. III. 2000. Email correspondence.

Hall, J. W. III., Baer, J. E., Chase, P. A. & Schwaber, M. K. 1994. Clinical application of otoacoustic emissions: What do we know about factors influencing measurement and analysis? *Otolaryngology- Head and Neck Surgery.*, 110(1):22-38.

Hall, A. J. & Lutman, M. E. 1999. Methods for early identification of noise-induced hearing loss. *Audiology.,* 38:277-280.

Hall, J. W. III. & Mueller, H. G. 1997. *Audiologists' desk Reference. Volume 1. Diagnostic audiology principles, procedures and protocols*. San Diego, London: Singular Publishing Group, INC.

Harris, F. 1990. Distortion-product otoacoustic emissions in humans with high frequency sensorineural hearing loss. *Journal of Speech and Hearing Research.,* 33:594-600.

Hatzopoulos, S., Mazzoli, M. & Martini, A. 1995. Identification of hearing loss using TEOAE descriptors: Theoretical foundations and preliminary results. *Audiology.,* 34:248-259.

Health Professions Council of South Africa. 2004. Internet: http://www.hpcsa.co.za. Access: 24 September 2004.

Henderson, D. & Hamernick, R.P. 1995. Biologic bases of noise-induced hearing loss. *Occupational Medicine.,* 10(3):513-534.

Hodge, D. C. & Price, G. R. 1978. Hearing Damage Risk Criteria. In D. M. Lipseomb (Ed.). *Noise and Audiology*. Baltimore: University Park Press.

Hong, O.S. & Kim, M.J. 2001. Factors associated with hearing loss among workers of the airline industry in Korea. *ORL Head Neck Nursing Journal.,* 19:7-13.

Hotaling, A. J., Blank, C. R., Park, A. H., Matz, G. J., Yost, W. A. & Raffin, M. J. M. 1994. Distortion-product otoacoustic non-emissions. *Paper presented at the 20th annual meeting of the American Auditory Society, Halifax.* Nova Scotia, Canada, 3 July.

Hotz, M. A., Probst, R., Harris, F. P. & Hauser, R. 1993. Monitoring the effects of noise exposure using transiently evoked otoacoustic emissions. *Acta Otolarngol.,* 113:478-482.

Howell, D.C. 1995. *Fundamental Statistics for the Behavioural Sciences 3rd Edition*. California: Duxbury Press.

Hsu, C.J., Chen, Y.S., Shau, W.Y., Yeh, T.H., Lee, S.Y. & Lin-Shiau, S.Y. 2002. Impact of activities of Na(+)-K(+)-ATPase and Ca2(+)-ATPase in the cochlear lateral wall on recovery from noise-induced temporary threshold shift. *Ann. Otol. Rhinol. Laryngol.,* 111(9):842-849.

Internet*:* http://www.agius.com. Access:3 June 2004

Internet*:* http://www.fmb.org.uk/publications/govtnews. Access: 21 May 2000.

Internet: http://www.faculty.ncwc.edu/toconnor. Access: 3 June 2004.

Internet: http://www.heartfoundation.co.za. Access: 3 November 2004.

Kahneman, D. 1973. *Attention and Effort.* Englewood Cliffs, New Jersey: Prentice Hall.

Katz, J. 1994. *Handbook of Clinical Audiology 4th Edition.* USA: Williams and Wilkens Press.

Kemp, D.T. 1978. Stimulated acoustic emissions from within the human auditory system. *Journal of the Acoustical Society of America.,* 64:1386-1391.

Kemp, D. T. 1982. Cochlear echoes: Implications for noise-induced hearing loss. In: Hammernik, R. P., Henderson, D. & Salvi, R. *New perspectives on noise-induced hearing loss.* New York: Raven, 189-207.

Kemp, D. T., Ryan, S. & Bray, P. 1990. A guide to the effective use of otoacoustic emissions. *Ear and Hearing.,* 11(2).93-105.

Khoza, K. & Ross, E. 2002. Auditory functioning in a group of adults infected with HIV/AIDS in Gauteng, South Africa. *South African Journal of Communication Disorders.,* 49: 17-27.

Kimberley, B. P. & Nelson, D. A. 1989. Distortion product emissions and sensorineural hearing loss. *Journal of Otolaryngology.,* 18:365-369.

Kim, D.O., Leonard, G., Smurzynski, J. & Jung, M.D. 1992. Otoacoustic emissions and noise-induced hearing loss: Human studies. In L.M.Dancer, D. Henderson, R.J.Salvi & R.P.Hamernick (Eds.), *Noise-induced hearing loss.* St Louis: Mosby Year Book Press.

Konopka, W., Pietkiewicz, P. & Zalewski, P. 2000. Otoacoustic emission examinations in soldiers before and after shooting. *Otolaryngologia Polska.,* 54(6):745-749.

Kopke, R.D., Coleman, J.K., Liu, J., Campbell, K.C. & Riffenburgh, R.H. 2002. Candidate's thesis: enhancing intrinsic cochlear stress defences to reduce noise-induced hearing loss. *Laryngoscope.,* 112:1515-1532.

Kowalska, S. & Sulkowski, W. 1997. Measurements of click-evoked otoacoustic emission in industrial workers with noise-induced hearing loss. *International Journal of Occupational Medicine and Environmental Health.,* 10(4):441-459.

Kryter, K. 1971. *The Effects of Noise on Man.* New York: Academic Press.

Kvaerner, K. J., Engdahl, B., Arnesen, A. R. & Mair, I. W. S. 1995. Temporary threshold shift and otoacoustic emissions after industrial noise exposure. *Scand. Audiol.,* 24:137-141.

Le Page, E. & Murray, N. 1998. Latent cochlea damage in personal stereo users: a study based on click-evoked OAEs. *MJA., 169:588-592*

Lonsbury-Martin, B. 1999. OAE Workshop. Pretoria, RSA: September 1999.

Lonsbury-Martin, B.L. & Martin, G.K. 1990. The clinical utility of distortion product otoacoustic emissions. *Ear and Hearing.,* 11:144-154.

Lonsbury-Martin B.L., Martin, G.K. & Telischi, F.F. 1994. Otoacoustic emissions in clinical practice. In F.E. Musiek, & W.F. Rinkelmann, (Eds.), *Contemporary perspectives in hearing assessment.* Boston: Allyn & Bacon.

Lonsbury-Martin, B.L., Martin, G.K. & Whitehead, M.L. 1997. Distortion product otoacoustic emissions. In M.S. Robinette. & T.J. Glattke, (Eds.), *Otoacoustic Emissions: Clinical Applications.* New York: Thieme.

Lonsbury-Martin, B. L., McCoy, M. J., Whitehead, M. L. & Martin, G. K. 1992. Otoacoustic emissions: Future directions for research and clinical applications. *The Hearing Journal.,* 45(11):47-52.

Lonsbury-Martin, B. L., Whitehead, M. L. & Martin, G. K. 1991. Clinical applications of otoacoustic emissions. *Journal of Speech and Hearing Research.*, 34:964-981.

Lucertini, M., Bergamaschi, A. & Urbani, L. 1996. Transient evoked otoacoustic emissions in occupational medicine as an auditory screening test for employment. *British Journal of Audiology.*, 30:79-88.

Lucertini, M., Moleti, A. & Sisto, R. 2002. On the detection of early cochlear damage by otoacoustic emission analysis. *Journal of the Acoustical Society of America.*, 111:972-978.

Marshall, L. & Heller, L. M. 1998. Transient-evoked otoacoustic emissions as a measure of noise-induced threshold shift. *Journal of Speech Language Hearing Research.*, 41:1319-1334.

Martin, G.K., Lonsbury-Martin, B.L., Probst, R., Scheinin, S.A. & Coats, A.C. 1987. Acoustic distortion products in rabbit ear canal. II. Sites of origin revealed by suppression contours and pure tone exposures. *Hearing Research.*, 28:191-208.

Mason, E. & Bramble, W. 1989. *Understanding and conducting research.* USA: McGrawill.

Melnick, W. 1994. Industrial hearing conservation. In J. Katz, (Ed.), *Handbook of Clinical Audiology 4th Ed.* Baltimore: Williams and Wilkins.

Miller, J.A. & Marshall, L. 2001. Monitoring the effects of noise with otoacoustic emissions. Internet: http://www.thieme-connect.com/ejournals/abstract. Access: 3 June 2004.

National Institute for Occupational Safety and Health. 1998. Criteria for a recommended standard: occupational noise exposure. DHHS (NIOSH) Publication: 98-126 Internet: http://www.cdc.gov/niosh/. Access: 9 December 2003.

Newby, H.A. & Popelka, G.R. 1985. *Audiology 5th Ed.* Englewood Cliffs: Prentice-Hall.

Nozza, R.J. & Sabo, D.L. 1992.Transient evoked OAE for screening school age children. *The Hearing Journal.,* 45 (11):29-31.

Occupational Safety and Health Act of 1993 (Act 85 of 1993) Internet: http://www.acts.co.za/ohs/index.htm. Access: 3 June 2004.

Oeken, J., Lenk, A. & Bootz, F. 2000. Influence of age and presbycusis on DPOAE. *Acta Otolaryngology.,* 120 (3): 396-403.

Oeken, I. & Muller, H. 1995. Distortion product otoacoustic emissions (DPOAEs) in chronic noise-induced hearing loss - recommendations for expert assessment. *Otolaryngology.,* 74(8): 473-480.

Office of Noise Abatement and Control. 1981. A Desk Reference to Health and Welfare Effects of Noise. U.S.A: National Association of Noise Control Officials. Internet: http://www.nonoise.org. Access: 9 December 2003.

Ohlms, L.A., Harris, F.P., Franklin, D.J. & Lonsbury-Martin, B.L. 1990. Distortion product emissions in humans III. Influence of sensori-neural hearing loss. *Ann otol Rhinol Laryngol.,* 99:30-42.

Osterhammel, P. A. & Rasmussen, A. N. 1992. Distortion product otoacoustic emissions: Basic properties and clinical aspects. *The Hearing Journal.,* 45(11):38-41.

Plinkert, P., Hemmer, W., Wagner, W., Just, K. & Zenner, H. P. 1999. Monitoring noise susceptibility: sensitivity of otoacoustic emissions and subjective audiometry. *British Journal of Audiology.,* 33:367-382.

Plinkert, P., Hemmert, W. & Zenner H.P. 1995. Comparison of methods for early detection of noise vulnerability of the inner ear. Amplitude reduction of otoacoustic emissions are most sensitive at submaximal noise impulse exposure. *HNO.,* 43(2):89-97.

Prieve, B., Gorga, M. & Neely, S. 1991. Otoacoustic emissions in an adult with severe hearing loss. *Journal of Speech and Hearing Research.*, 34:379-385.

Prieve, B., Gorga, M., Schmidt, A., Neely, S., Peters, J., Schultes, L. & Jestead, W. 1993. Analysis of transient-evoked otoacoustic emissions in normal-hearing and hearing-impaired ears. *Journal of the Acoustical Society of America.,* 93:3308-3319.

Probst, R., Lonsbury-Martin, B. L. & Martin, G. K. 1991. A Review of oto-acoustic emissions. *Journal Acoustic Society of America.,* 89(5):2027-2067.

Probst, R. & Harris, F. P. 1993. Transiently evoked and distortion-product otoacoustic emissions- comparison of results from normally hearing and hearing-impaired human ears. *Archives of Otolaryngology.,* 119:858-860.

Probst, R., Harris, F. P. & Hauser, R. 1993. Clinical monitoring using otoacoustic emissions. *British Journal of Audiology.,* 27:85-90.

Probst, R. & Hauser, R. 1990. Distortion product otoacoustic emissions in normal and hearing-impaired ears. *American Journal of Otolaryngology.,* 11:236-243.

Reshef, I., Attias, J. & Furst, M. 1993. Characteristics of click evoked otoacoustic emissions in ears with normal hearing and with noise-induced hearing loss. *British Journal of Audiology.,* 27:387-395.

Robinette, M. S. 1992. Clinical observations with transient otoacoustic emissions with adults. *Seminars in Hearing.,* 12(1):23-26.

Robinette, M.S. & Glattke, T.J. 1997. *Otoacoustic Emissions: Clinical Applications*. New York: Thieme.

Roede, T., Harris, F. P., Probst, R. & Xu, Z. 1993. Repeatability of distortion product otoacoustic emissions in normally hearing humans. *Audiology.,*32 (5):273-81.

Rosen, E.J., Vrabec, J.T. & Quinn, F.B. 2001. Noise-induced hearing loss. Grand Rounds presentation, UTMB, Department of Otolaryngology. Internet: http://www.utmb.edu. Access: 9 December 2001.

Sataloff, J. & Michael, P. 1973. *Hearing Conservation*. Springfield, I.L.: Charles C. Thomas.

Silwinska-Kowalska, M. 1998. The role of evoked and distortion-product otoacoustic emissions in diagnosis of occupational noise-induced hearing loss. *Journal of Audiological Medicine.*, 7(1):29-45.

Sliwinska-Kowalska, M. & Kotylo, P. 1997. Is otoacoustic emission useful in the differential diagnosis of occupational noise-induced hearing loss? *Medycyna Pracy.*, 48(6):613-620.

South African National Standard. 2004. The measurement and assessment of occupational noise for hearing conservation purposes. SANS. 10083:2004. Ed.5.

South African Society of Occupational Medicine (SASCOM). 2004. Baseline Audiometry in the period following 16 November 2003. Email from (naidoot@umthombo.wits.ac.za). 19 July 2004.

Subramaniam, M., Henderson, D. & Spongr, V. 1994. The relationship among distortion-product otoacoustic emissions, evoked potential thresholds, and outer hair cells following interrupted noise exposures. *Ear and Hearing.*, 15:299-309.

Suckfüll, M., Schneeweb, S., Dreher, A. & Schorn, K. 1996. Evaluation of TEOAE and DPOAE measurements for the assessment of auditory thresholds in sensorineural hearing loss. *Acta Otolaryngologica (Stockholm).*, 116:528-533.

Sutton, L. A., Lonsbury-Martin, B. L., Martin, G. K. & Whitehead, M. L. 1994. Sensitivity of distortion-product otoacoustic emissions in humans to tonal over-exposure: Time course of recovery and effects of lowering L2. *Hearing Research.,* 75:161-174.

Tognola, G., Grandon, F., Avan, P., Ravazzani, P. & Bonfils, P. 1999. Frequency specific information from click evoked oto-acoustic emissions in noise-induced hearing loss. *Audiology.,* 38:243-250.

Vendantum, R. & Musiek, F. E. 1991. Click evoked otoacoustic emissions in adult subjects: Standard indices and test-retest reliability. *American Journal of Otology.,* 12(6):435-442.

Vinck, B. M., Van Cauwenberge, P. B., Leroy, L. & Corthals, P. 1999. Sensitivity of transient evoked and distortion product otoacoustic emissions to the direct effects of noise on the human cochlear. *Audiology.,* 38:44-52.

Wang, Y.F., Wang, S.S., Tai, C.C., Lin, L.C. & Shiao, A.S. 2002. Hearing screening with portable screening pure tone audiometer and distortion product otoacoustic emissions. Zhongua Yi Xue Za Zhi (Taipei), 65(6):285-292: Internet: http://www.ncbi.nlm.nih.gov. 3 June 2004.

Weiten, W. 1992. *Psychology: themes and variations 2nd Ed.* California: Brooks/Cole.

Xu, Z. M., Vinck, B., DeVel, E. & Van Cauwenberge, P. 1998. Sensitive detection of noise-induced damage in human subjects using transiently evoked otoacoustic emissions. *Acta Otolaryngologica.,* 52:19-24.

Yeo, S.W., Park, S.N., Park, Y.S. & Suh, B.D. 2002. Effect of middle ear infusion on otoacoustic emissions. *Journal of Laryngology Otol.,* 116(10): 794-799.

Appendix A: Informed consent form

Background information and request for consent of workers asked to participate

This form is to be administered to selected workers before their participation in audiometric and otoacoustic emission testing by the audiologists

Read the following to each prospective subject, pausing to answer any questions:

This mine has agreed to help the SIMRAC research team investigate how certain hearing tests might be used to identify noise-induced hearing loss before it becomes serious and causes problems. Information from the study will be used to decide if changes can be made to normal testing procedures that will allow early identification of hearing losses caused by noise, in order to improve workers' health and safety. The study has been approved by the Union, because all of the workers who agree to participate will remain unanimous, and the results will be used to help protect workers from noise.

If you agree to participate, we will ask you some questions about you, your job and the noise in places on the mine where you work. We will also ask you questions about your hearing and what you do to protect it. For example, you will be asked what kind of hearing protection devices (HPD) you use and when you use them.

Your hearing will then be tested in the normal way, after which some special tests will be used to check your hearing. Comparisons will be made between results from the normal tests and from the special tests, to find out if the special tests would be better for identifying hearing loss caused by noise.

The experiment is not meant to check your hearing, but to find out the best way of testing ears. Accordingly, the tests and the results will have no effect on your job, and will have nothing to do with compensation. Your test results will be kept confidential, and only you and the research team will be able to look at them. The results will be used to find out which one of the different tests is best for identifying noise-induced hearing loss early, before it causes problems.

We will explain to you the way each test is done, we will show you the results and we will explain what they mean. Some of the tests will be done more than once, to double-check on the results.

We will keep your name and any information you tell us in strict confidence, and not tell the mine or the managers anything about you or your test results.

Your participation in the study is voluntary. If you do not want to take part, it will not affect your job in any way. If you do decide to take part, this will also not affect your job in any way, but will be helpful to all workers who are working in the noise. We ask that you decide for yourself whether you want to participate, and if you have some questions that need to be answered before you decide, please ask them.

Will you help us with this research? (YES or NO)

If NO, ask the next worker. If YES, ask worker to sign or make a mark in the space below to indicate that he has been given the information and understands it. Then record the other details.

I have been told about the study and have been given the chance to ask questions about it and about my participation. I also understand that if I have any questions at any time, they will be answered, and that if I am not satisfied with the answers I can withdraw from the study.

Name:…………………………………….. Company number:
………………………….

Date:………………………..

Subject questionnaire

Industry No. ______________________________________

Study No. ______________________________________

Date. ______________________________________

Date of birth ______________________________________

Mine ______________________________________

1 Work history

(Occupational noise exposure)

Duration (years)	Occupation

2 Hearing protection

2.1 Do you work in a noisy area?

□Yes □No

2.2 Do you wear hearing protection devices?

□Yes □No

2.3 When do you wear hearing protection devices?

□I never use HPDs

□I rarely use HPDs

□I only use HPDs when the noise is bad

□I use HPDs all the time while doing my job

2.4 What type of hearing protection devices do you use?

□None: do not use HPDs

□Band-mounted earplugs

□Re-usable earplugs

□Disposable earplugs

□Custom-moulded earplugs

□Earmuffs

□Earplugs and earmuffs together at the same time

2.5 What training have you had for using HPDs?

□ Only instructions or orders to use HPDs when in noise

□ Group instruction in the correct use of HPDs

□ Individualised instruction in the correct use of HPDs

2.6 What choice were you given for the type of HPDs you use?

□No choice: only one type of HPD was offered

□Allowed to choose from two different types of HPDs

□Allowed to choose from several different types of HPDs

2.7 Were you given any individualised assistance or instruction in choosing the type of HPDs you use?

□Yes □No

2.8 How comfortable are the HPDs you are using?

□Uncomfortable and I do not like to use them

□Uncomfortable, but not so bad that I am discouraged from using them

□Comfortable

2.9 How effective are the HPDs you are using in keeping out the noise?

□Most of the noise gets in when I am wearing my HPDs

□Some of the noise gets in when I am wearing my HPDs

□Most of the noise is kept out when I am wearing my HPDs

2.10 How can you obtain replacements for your HPDs if they are lost or damaged?

□From a dispensing point or official on surface, but only after explaining why replacements are needed

□From a dispensing point or official on surface, without explaining why replacements are needed

□From shift supervisor/shift boss during the shift

□From crew supervisor or team leader during the shift

3 Ear operations ______________________________________

____

4 Middle ear problems (discharge, pain, perforated eardrum)

____

____

5 Tinnitus: Constant/Only at work/Left ear/Right ear

____

6 Injuries to head or ears ____________________________________

____

____

7 Medicine taken at present/previously

(Malaria, TB, ICU, Chemotherapy, Hospitalisation)

____

____

8 Family history of hearing problems

____

____

Otoscopy results

LANDMARKS	**RE/LE**	CERUMEN	**RE/LE**
Cone of light	________	Occluding	________
Minimal	________	Minimal	________
Excessive	________	Excessive	________
None	________	None	________

TYMPANIC MEMBRANE **RE**	**LE**	EXTERNAL CANAL	**RE**	**LE**
Normal	________	Normal	________	
Dull	________	Reddened/Swollen	________	
Perforated	________	Foreign Body	________	
Scarring	________	Growth	________	
		Drainage (describe)	________	
		Blood Present	________	
		Collapsed	________	

COMMENTS:

____

____

Immittance results

	RE	LE
Compliance	________	________
Volume	________	________
Pressure	________	________

Audiometry results

Screening

kHz Left ear							kHz Right ear						
0,5	1	2	3	4	6	8	0,5	1	2	3	4	6	8

Diagnostic

kHz Left ear							kHz Right ear						
0,5	1	2	3	4	6	8	0,5	1	2	3	4	6	8

Oto-acoustic emission test results

	Test 1	Test 2		Test 1	Test 2
TE Diagnostic	☐	☐	DP diagnostic	☐	☐
TE Screening	☐	☐	DP Screening	☐	☐

Appendix B: Calibration certificates