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Hearing protection in mines: Evaluating the Noise Clipper® custom made hearing protection device.

by

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O Heavenly Father,

Guardian of the deaf,

Grant an Audiologist's humble prayer:

"Make me worthy of those determined men

Whose ingenuity conceived this Science.

Let me be meticulous in all I do-

Have patience infinite with understanding too;

May I in new technologies remain abreast-

Inspire trust and offer but the best;

Thus can I place within my patients' reach

The Joy of sound – the means of hearing speech"…

Amen.

Arnold Rieck

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Abstract

Title: Hearing protection in mines: Evaluating the Noise Clipper® custom made hearing protection device

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Degree: M.Communication Pathology

Noise induced hearing loss has been extensively researched and commented on, yet it remains prevalent among industrial workers. The real-world attenuation properties of the Noise Clipper® custom-made hearing protection device and the comfort levels it afford are unknown. Furthermore, research in hearing conservation is seldom focused on the critical/biological thresholds for temporary threshold shift. Field studies on hearing protection devices have demonstrated that laboratory derived measures bear little relation to attenuation achieved in workers. Research has consistently demonstrated that noise reduction ratings that are derived from the laboratory real-ear-at-threshold method do not accurately represent the attenuation of noise that these devices actually provide and the matter remains unclear. Too many important variables are neglected in current real-ear-at-threshold evaluation protocols. This study used an alternative method, the microphone-in-real-ear approach where a dual-element microphone probe was inserted into the Noise Clipper® to measure noise reduction by recording the difference in noise levels outside and behind the device. The sub aims of the study were to record ambient noise levels and frequency spectra; to determine the attenuation characteristics; and to compare the attenuation thresholds to biological thresholds for temporary threshold shift. Using this protocol, measurements were made on 20 subjects in real world situations in order to match the attenuation characteristics of the Noise Clipper® to the actual noise exposure. The microphone-in-real-ear derived attenuation thresholds were compared to the real-ear-at-threshold values provided by the manufacturer of the Noise Clipper®. Additional sub-aims were to determine the comfort levels of the Noise Clipper® and record the self-reported wearing time of the device. Wearing comfort was evaluated using a bipolar rating scale. The researcher interviewed 240 mine workers at a platinum mine. Several comfort related sub-scales were used to quantify reported comfort levels. Simultaneously, usage time of the device was self-reported by each worker. Results of the microphone-in-real-ear

measurements indicated that ambient noise levels fluctuated from day to day. The attenuation results indicated that most of the measurements suggested protection against noise induced hearing loss through the use of the Noise Clipper®. It was found that the REAT results over estimated the attenuation ability of the Noise Clipper® when compared to the results of the F-MIRE measurements. Eighty seven percent of the measurements indicated protection from thresholds below the biological threshold for temporary threshold shift. Seventy five percent of the workers indicated that the Noise Clipper® was comfortable to wear and 79% indicated that they used it for a full eight hour shift. The results provide an opportunity to assess the use of a protection device and its effectiveness among mineworkers combined with information regarding noise exposure levels. The findings highlight the importance of evaluating variability in terms of individual-specific protection.

Key terms: *biological threshold for temporary threshold shift; comfort levels; custom made hearing protection devices; hearing protection; microphone-in-real-ear protocol; noise induced hearing loss; noise reduction; permanent threshold shift; temporary threshold shift*

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List of abbreviations

ACU: Attenuation control unit

APV: Assumed protection value

AT: Acoustic trauma

CHPD: Custom-made hearing protection device

CI: Comfort index

dB: Decibel

HC: Hearing conservation

HCP: Hearing conservation program

HPD: Hearing protection device

Hz: Hertz

IHC: Inner hair cells

LAeq,8h: A-weighted equivalent continuous sound

MIRE: Microphone in real ear

NCE: Noise control engineering

NIHL: Noise-induced hearing loss

NRR: Noise reduction rating

OHC: Outer hair cells

Pa: Pascal

PAR: Personal attenuation rating

PC: Personal computer

PHL: Permanent hearing loss

PLH: Permanent loss of hearing

PTS: Permanent threshold shift

QWL: Quality of work life

REAT: Real ear at threshold

RTA: Real time analysis

RTM: Real time measurement

SIMRAC: Safety in mines research commission

SPL: Sound pressure level

TFOE: Transfer function of the ear

TTS: Temporary threshold shift

TWA: Time weighted average

TU: Time of usage

WHO: World Health Organization

Chapter 1

Introduction

1.1 Introduction and background

The industrial revolution has caused hazardous noise to be more prominent than any other noxious agent found in industry (Rink, 1996, p.9). Noise-induced hearing loss (NIHL) is probably the most elaborately defined and extensively researched of all the effects of noise on the human ear (Suter, 1991, p.14). It is also the most prevalent irreversible occupational hazard in the world (World Health Organization, 2003, p.39) and is according to Rabinowitz (2000, pp. 2749-2760) virtually 100 percent preventable. The World Health Organization (WHO) defines the adverse effects of noise as follows: "an adverse effect of noise is defined as a change in the morphology and physiology of an organism that results in impairment of functional capacity, or an impairment of capacity to compensate for additional stress, or increases the susceptibility of an organism to the harmful effects of other environmental influences" (WHO, 2003, p. 39).

Worldwide, the incidence of NIHL is so serious that the WHO and the International Labour Organization placed it on their priority list of major work-related illnesses (Steenkamp, 2003, p. 91).

Exposing workers to excessive noise can limit their ability to communicate and to hear warning signals, it increases job dissatisfaction, performance errors, loss of productivity and increases risk of workplace accidents. Inadequate noise control may potentially have an immediate negative impact on safety and productivity. Of greater concern, however, are the implications that hearing loss may have for the health of workers, on employment prospects and on overall quality of life (Franz, Van Rensburg, Marx, Murray-Smith, & Hodgson, 1997, p. 5).

Numerous studies have been done and working groups have been formed to address the core problem of workers suffering permanent loss of hearing because of excessive exposure to noise at their place of work (Berger, 2005, p.51). Elliott Berger of E-A-R 3M compiled a bibliography of more than 2500 articles concerning hearing protection, hearing conservation and aural care. Highly respected researchers in the fields of otolaryngology, acoustics, occupational hygiene, audiology, hearing conservation, and hearing protection device (HPD) manufacturers performed most of the relevant studies. From these studies, knowledge is gained about hearing conservation programmes (HCPs), HPDs, effects of noise on hearing and productivity, needs for education concerning hearing protection and hearing conservation in general. Given this corpus of knowledge, one would expect that the core problem of hearing loss due to noise exposure

would have been addressed successfully. Although NIHL is the most widespread occupational disease, its insidious nature creates an inability to detect it early and prevent progression.

Vast amounts of money are being spent on education and training of management and workers alike, and yet the incidence of the condition is higher today than ever before (Steenkamp, 2001, p. 6). The Safety in Mines Research Committee (SIMRAC) has to date spent more than R350 000 000 on safety and health research issues in the mining industry alone (Prichard, 2001, p. 2). It has been estimated that between 68% and 80% of mine workers are exposed to a time-weighted average noise level of 85 dB(A) or higher, indicating a significant risk for developing hearing loss for the majority of the industry's personnel (Franz & Phillips, 2001, p.195). The primary concern of the audiologist dealing with noise-exposed workers is the prevention of permanent NIHL.

HPDs continue to be of primary importance in the fight against NIHL. To understand how these devices work and how they are evaluated and to determine their actual performance and protection potential are of great importance for the audiologist dealing with the population exposed to noise (Hager, 2004, p. 1). There is an urgent need for information and research to develop actions that would address and remediate the underlying problems of hearing conservation. There is also a need for information to guide any actions in a constructive and efficient manner (Daniell, Swan, Camp, McDaniel, Cohen, Stebbins & Lea, 2005, p.1). The proper selection of HPDs is critical for effective hearing loss prevention (Hager, 2007, p. 26).

Although the majority of hazardous working conditions, including noise pollution, can be avoided or controlled through effective health and safety programs **"**silent diseases", involving tragic human cost still occur worldwide (Steenkamp, 2001, p. 6). Noise control engineering (NCE) will always be the first priority (also referred to as the first defense), in a HCP (Steenkamp, 2003, p. 91). However, its limitations and administrative control are well known and it could become both complex and costly, depending on the situation, or it may even be impossible to implement (Bennett, 1998, p. 27; Melnick, 1994, p. 545; Steenkamp, 2003, p. 91). Because of these complexities "there is a general trend away from the more proven method of using engineering controls to the less proven technique of personal HPDs" (Durkt 1998, p. 2**)**. The use of hearing protection devices are easier to implement and less expensive than engineering controls (Durkt, 1998, p. 2**).** Custom-made hearing protection devices (CHPDs) are implemented on a large scale in the South African mining industry. One such protector is the Noise Clipper® CHPD. Since there is an increase in usage of CHPDs, questions have been raised pertaining to its effectiveness when worn in a working environment. This device has been tested by the South African Bureau of Standards (SABS) using the real ear at threshold method

(REAT) that is a subjective laboratory controlled insertion loss measurement.

Throughout literature it is found that laboratory evaluations have not proven to predict the real-world attenuation of HPDs (Behar, 2007, p. 2; Berger, 2007, p. 1; Niquette, 2007, p. 4; Vinck, 2007, p. 15; Franks, Murphy, Harris, Johnson, & Shaw, 2003, p. 502; Nelisse, Gardreau, Boutin, Voix, & Laville, 2007, p. 18). Scientific research has extensively and consistently demonstrated that noise reduction ratings (NRRs) are in no way an accurate representation of actual real-world attenuation of workplace noise. Variables such as individual fit, insertion or application techniques, training, real-world attenuation, comfort levels and leak-tightness are not measured in the current evaluation protocols (Vinck, 2007, p. 15). Real-world attenuation properties and comfort levels afforded by CHPDs are relatively unknown. The attenuation obtained from these devices during high noise exposure is unclear (Vinck, 2007, p. 15).

Field studies on HPDs have consistently demonstrated that laboratory derived measures bear little relation to attenuation achieved by workers in the field. Hager (2002, p. 2) is outspoken on this issue when he remarks: **"**not only are the real-world values far less than the lab says, but they do not even correspond"**.** Berger (2000, p. 1) compared the laboratory versus real-world attenuation differences of sixteen HPDs. Not one of these devices' real-world attenuation performances correlated with their manufacturers' claimed NRRs. With these grave differences, the existing methods used for measuring such devices' attenuation are questionable and prediction of a HPD performance with a great degree of certainty appears to be minimal (Durkt, 1998, p.19)

Berger, Franks and Lingren (1996, p. 368) compared the laboratory test results of HPDs with 22 real-world studies and found overestimations on attenuation of between 140% and 2000%. Existing approaches on attenuation measurements are highly criticized throughout literature (Hager, 2002, p. 1; Neitzel & Seixas, 2005, p. 227; Neitzel, Somers & Seixas, 2006, p. 2 and Vinck, 2007, p. 19).

The greatest criticism on the existing methods of attenuation measurements is the test itself (Vinck, 2007, p. 22). Several methods of measuring HPD attenuation exist. Berger, Voix and Kieper (2007, p. 3) categorize field test methods as follows:

- Subjective methods-REAT and Loudness balance
- Objective-MIRE
- Non-acoustic-pressure/ seal test measurements

The psychophysical method that is referred to as the "real-ear-at-threshold" (REAT) is described by Lancaster and Casali (2004, p. 5) and also by Berger (2005, p.53) as a subjective

measuring protocol. It is the method most commonly used in assessing passive attenuation (Cro, 1997, p. 7). This method is conducted in carefully controlled laboratory situations and performed by trained experimenters on informed subjects. Human factors involved in the use of HPDs in real-world situations are not addressed by the current attenuation test protocols. The variables not evaluated, as described above, will have a detrimental effect on real-world performance and consistent use of HPDs (Hager, 2002, p. 2; Neitzel & Seixas, 2005, p, 227; Vinck, 2007, p. 18). The alternative method of attenuation measurement is referred to as the "physical" or "objective" method. One way of implementation of this method is to use a microphone mounted in a test fixture, such as a KEMAR mannequin, while the other way is to use a microphones-in-real-ear (MIRE) technique to measure attenuation. Some of the advantages of this method are that measurements are conducted in elevated noise levels (high loads as found in industrial workshops) and that the results are not contaminated by physiological noise as is found with the REAT method (Vinck, 2007, p. 20). Other advantages of the MIRE method are that the measurements are much quicker to conduct and it can account for individual differences in the fit of the HPD (de Muynck, 2007, p. 227). The non-acoustic test method is not a viable field measurement "except for possibly a pass/failed determination" for selected types of HPDs (Berger et al., 2007, p.3). This method was primarily used to validate the fit and seal tightness of CHPDs (Berger, et al. 2007, p.3).

Arezes and Miguel (2002, p. 532) remarked that the acoustical attenuation properties are not the only characteristics of a HPD that protect a worker from industrial hearing damage. Other important ergonomic features should also be taken into account such as comfort, need for verbal communication (elimination of over protection), durability, signal detection, compatibility with other safety equipment, maintenance and cost.

This study will attempt to answer the following questions:

- What is the Noise Clipper® CHPD's attenuation effectiveness when used in normal working conditions?
- What is the workers perception concerning comfort levels afforded by the Noise Clipper® CHPD?

The methods used to investigate these questions were to physically measure the ambient noise levels and noise reduction of the Noise Clipper® CHPD in a normal working environment, using the F-MIRE protocol while comfort levels were determined by using a bi-polar comfort rating scale administered by the researcher in a one-to-one setting.

1.2 Definition of terms

Action level

Action level is an 8-hour time-weighted average of 85 decibels measured on the A-scale (dBA). It is a noise exposure level at which an employer is required to take certain steps to reduce the harmful effects of noise on hearing. The Occupational Safety and Health Administration (OSHA) define an action level as exposure to a dangerous situation, such as excessive noise, lead or hazardous materials. When information indicates that employee's exposure exceeds this requirement, the employer must utilize a monitoring program (OSHA, 1983).

Attenuation control unit

The attenuation control unit is supplied by Ergotec Netherland. It is a test developed for the verification of leak-tightness of a hearing protector device. The unit is specifically developed for the evaluation of leak-tightness of custom-made hearing protection devices.

Biological threshold for temporary threshold shift (BT for TTS)

"The critical levels for temporary threshold shift define the so-called safe levels of noise or acoustic injury thresholds" *(*Mills & Going, 1982, p. 120). The critical levels are referred to as the Biological threshold for temporary threshold shift (De Muynck, 2007, p. 221). The critical levels of noise differ in intensity for different frequencies. The critical level of noise centred at 4000 Hz is 74 dB SPL, 78 dB SPL for 2000 Hz, 82 dB SPL for 1000 Hz and 500 Hz, 86 dB SPL for 250 Hz and 96 dB SPL for 125 Hz *(*Mills & Going, 1982, p. 120).

Hearing conservation

Hearing conservation is the prevention or minimization of NIHL by the control or reduction of noise through engineering controls, administrative measures and/or, as a last resort, the issuing of personal protection in the form of suitable hearing protection devices, as well as hearing loss prevention procedures. (SANS 10083, p. 11, 2004).

Hearing protection device

HPD devices are intended to control the transmission of sound energy from any given source to the cochlea of the exposed worker (Bennett, 1998, p. 27; Chandler, 2001, p. 1). These devices can be categorised into conventional and custom-made devices. Two main types of conventional devices are used, namely, earmuffs and earplugs and the latter are most often disposable. The custom-made devices are also termed otoplastics (De Muynck, 2007. P. 226).

Insertion loss

This measurement is often referred to as a hearing test with and without a hearing protector in the ear. This term describes the process in which a single stationary microphone is used and two measurements are performed, one with the ear isolation device (hearing protector)

in place and one without the device. The attenuation is the difference between the two measurements, hence the phrase "insertion loss"; it is the reduction (or loss) in the noise level after the insertion of a barrier (the ear isolation device) between the noise source and the location of measurement (Lancaster & Casali, 2004, p. 4).

Leak-tight verification test

The attenuation control unit is connected to the otoplastic that is placed in the subject's ear canal. An overpressure of 10 mbar is generated by the attenuation control unit in the cavity between the otoplastic and the tympanic membrane. When a stable system is measured over three seconds (with overpressure of 10 mbar in the cavity), the test is described as positive and verifies the otoplastics leak-tightness. Should the system become unstable over three seconds the leak-tight test result is negative. The results are displayed on a digital screen and can be recorded for later analysis (De Muynck, 2007, p. 227).

Microphones-in-real-ear (MIRE)

The MIRE attenuation protocol is an objective method of *in situ* measuring of the noise reduction of a HPD. The MIRE probe that contains two microphones is inserted into the centre bore of a custom-made earplug. The reference microphone measures the sound pressure outside, while the measurement microphone registers the sound pressure behind the HPD in the subject's ear canal (Bockstael, Botteldooren & Vinck, 2010, p.2).

Noise-induced hearing loss (NIHL)

Noise induced hearing loss (NIHL) is the most prevalent irreversible occupational hazard in the world (WHO, 2003:39) and is virtually 100% preventable (NPC Hearing, 2006, p.2, Rabinowitz, 2000, p. 2749). With prolonged noise exposure, the outer and inner hair cells of the cochlea are either partly or totally impaired leading to partial or non-conduction of sound (WHO, 2003, p. 39), hence "noise-induced hearing loss".

Noise reduction

A measurement that utilizes two microphones with the measurements made simultaneously on the interior and exterior sides of the HPD (Lancaster & Casali, 2004, p. 4).

Insertion loss (IL) and Noise reduction (NR) are "equivalent quantities" though the difference between these two measurements is due to a diffraction effect, such as the transfer function of the open ear (TFOE). The TFOE is a value obtained by calculating the difference in sound level between the inner and outer microphone locations used when making NR measurements. To make IL and NR "equivalent," NR must be adjusted for the TFOE effect since it is not present for IL measurements (Perala, 2006, p.10).

Sound pressure

Sound pressure (acoustic pressure) is the measurement in the unit Pascal of the root mean square pressure deviation (from atmospheric pressure) caused by a sound wave passing through a fixed point and is the sound pressure expressed as a decibel value. Sound pressure is also expressed in micro Pascal (µPa). The lowest sound pressure difference that can be heard by the human ear when the sound is a pure tone with a frequency of around 2000 Hz is 20µPa. "Thus an SPL of 0 dB does not mean that there is no sound pressure or sound but rather that the sound pressure is the same as the reference level, Pref, at 20 µPa (20 x 10-6 Pa)" (Williams, 2009, p. 37).

1.3 Chapter layout

Chapter 1 (Introduction): The purpose of this chapter is to provide an introduction and rationale for the research project that culminates in the research question. This is followed by the declaration of terminology and an outline of the contents of the chapters.

Chapter 2 (Background): This chapter provides an overview of hearing conservation, the primary and secondary effects of noise on the human ear, NIHL, HPDs and legislature on hearing conservation. Measurement effectiveness of HPDs is discussed and the REAT and MIRE protocol techniques are evaluated.

Chapter 3 (Methodology): This chapter aims to provide a concise background of the methodology used in this study. The main aim and sub-aims are formulated to answer the research question that is posed. The research design, sample population and selection criteria, materials and apparatus used in the study, pilot study, data collection procedures and data analysis are discussed in detail.

Chapter 4 (Results): The aim of Chapter 4 is to present the results of the study. Statistical findings and the significance thereof are analyzed and commented upon with regard to the main and sub-aims of the study.

Chapter 5 (Discussion of results): In this chapter the results according the sub aims of the study are discussed. Comments are given on findings and compared to existing research outcomes found in literature.

Chapter 6 (Conclusions, limitations and recommendations): In this chapter the conclusions, limitations and recommendations based on the research findings of this study are presented in relation to the initial background of existing research results.

Chapter 2

Theoretical Background

In this chapter, an overview is given of the effects of noise on the human ear, HCPs and legislation, HPDs and the measurement of their effectiveness.

2.1 Introduction

Since sound energy exerts powerful effects, it needs to be managed with care. It is known that unwanted noise (noise pollution) destroys auditory and sensory cells of the cochlea, thus causing hearing damage that cannot be reversed by any medical or surgical procedures presently known (Franks 2001, p. 1). In order to understand the serious urgency for hearing conservation it is important to know the physical effects that noise have on the human ear without the use of HPDs.

2.1.1 The effect of noise on the human ear

To understand the effect that noise has on the human ear the characteristics of sound need to be explained. Morphological changes are found in the inner and outer cilia of the cochlea where the stereo-cilia become fused and bent. With prolonged exposure to noise the outer and inner hair cells are destroyed, leading to the non-conduction of sound after noise exposure (WHO, 2003, p. 39). The risk for NIHL increases when noise combines with exposure to vibration, the use of ototoxic drugs or exposure to certain chemicals (WHO, 2003, p. 41).

The energy of sound may be expressed as sound power or sound pressure. “A scale suitable for expressing the square of the sound pressure in units best matched to subjective response is logarithmic rather than linear. Thus the Bell was introduced which is the logarithm of the ratio of two quantities, one of which is a reference quantity” (Hansen (2001, p.30). The basic unit, the Bell, is multiplied by 10 to render the unit “decibel” (dB). The decibel is a dimensionless logarithmic unit for both sound power and sound pressure (Franz, 2002, p. 5).

The range of sound pressures that can be heard by the otologically sound human ear is very large and ranges between 20 Hz to 20,000 Hz although it is more sensitive to frequencies in the range 1000 Hz to 5000 Hz. This is the frequency range normally associated with speech discrimination (Williams, 2009, p. 36). Hansen (2001, p.30) describes the “minimum acoustic pressure audible to the young human ear judged to be in good health, and unsullied by too much exposure to excessively loud music, is approximately 20×10^{-6} Pa, or 2×10^{-10} atmospheres (since 1 atmosphere equals 101.3×10^{3} Pa). The minimum audible level occurs at about 4,000 Hz and is a physical limit imposed by molecular motion”.

The frequencies of noise are relevant, because:

- It determines the scope for controlling noise, since low frequency sound travels further and is more difficult to attenuate/isolate/exclude than high frequency sound (Franz, 2002, p. 5).
- The damaging effect of noise at a given level (power or pressure) varies with frequency, because the ear is less sensitive to low frequency sound and therefore not as susceptible to damage as is the case for high frequency noise (Franz, 2002, p. 5).

2.1.2 Mechanisms of noise induced damage

Unwanted noise can affect the ear in different ways, namely temporary threshold shift (TTS), permanent threshold shift (PTS), acoustic trauma and otitic blast injuries (Dancer, 2004, pp. 4-7; Melnick, 1994, p. 536; Rosen, 2001, p. 2).

2.1.2.1 Temporary threshold shift (TTS)

When acoustic pressure is delivered to the entrance of the cochlea via the ossicular chain, the basilar membrane and the organ of Corti become displaced. The displacement of the two membranes, the basilar and tectorial generates a shearing motion of the outer and inner hair cells stereocilia. The relative shear between the tectorial membrane and the hair cells' apical parts produced by basilar membrane motion is the primary source of mechanical input to the cochlear hair cells during acoustic stimulation. The displacement of stereocilia modulates their transducer conductance (Syka, 2002, p. 601). The shearing motions induce a release of neurotransmitters (glutamate) at the basal end of the inner hair cells when ion channels are opened and cells depolarized. The afferent nerve fibres, that connect the inner hair cells, convey the information to the upper auditory pathways (Dancer, 2004, p.4). Exposure to intense noise induces two major types of damage to the inner ear: mechanical and/or metabolic. Two major types of damage to the inner ear can occur with exposure to intense noise namely mechanical and/or metabolic:

- Mechanical damage: for normal hearing thresholds “the amplitude of the *passive* displacements of the tip of the stereocilia is about 10-12 m (1/10,000 the diameter of a stereocilium, 1/100 the diameter of the hydrogen atom). At 120 dB this amplitude reaches 1 micrometer (corresponding to an angular deflexion of 10 to 20 degrees), thousands times per second” Dancer (2004, p.4). The noise level can either cause the stereocilia to break off immediately especially in the presence of high intensity impact noise or it can be overpowered by fatigue breakdown mechanisms. Following the exposure to high intensity noise, the rigidity or firmness of the stereocilia decreases and a” de-polymerisation of the skeleton of actin

filaments and/or a shortening of their roots and/or a downward shift of the interciliary links. These changes (that are usually reversible) yield to a lower efficiency of the working of the ion channels and to a decrease of the sensitivity of the cochlea that corresponds to a Temporary Threshold Shift (TTS)" (Dancer, 2004, p. 5). The outer hair cells (OHC) are the most susceptible to ototoxicity, hypoxia and noise. In the normal cochlea the OHCs are responsible for frequency selectivity and sensitivity at threshold. It contains prestin, a protein that allows these cells to act like "piezoelectric elements" and have a selective amplification of the acoustic stimulus that is transmitted to the inner hair cells (IHC) and then transduced into nerve signals of the afferent system. A 40 dB loss in hearing sensitivity will be present with the destruction of the OHCs and will lead to the impairment of frequency selectivity and recruitment (Dancer, 2004, p.6).

- Metabolic damage: this type of damage is described by Dancer (2004, p. 6) as a swelling of the afferent synapses found immediately after the exposure to a loud noise due to an excessive release of neurotransmitters in the synaptic slit (glutamatergic excitotoxicity). In some instances, the synapses burst out of the afferent nerve fibres and disconnect from the IHCs. Dancer (2004, p. 6) observed a recovery (neo-connections) starting 24 hours after the end of the exposure and being almost complete five days later and explains that "this type of damage is responsible for a large part of the Temporary Threshold Shifts (especially in case of exposure to loud continuous noises)". Although most of the IHCs and synapses recover some will not recover at all. Kujawa and Liberman (2009, p. 14077) observed that although cochlear sensory cells remain intact after recovery from TTS, acute loss of afferent nerve terminals and delayed degeneration of the cochlear nerve was present and remarked that cochlear damage caused by noise leads to "progressive consequences that are considerably more wide spread than are revealed by conventional threshold testing". TTS may also be accompanied by tinnitus, perceived as a ringing sound in the ears.

Chen, Dai, Sun, Lin and Juang (2007, p. 528) conducted a study to evaluate the combined effects of noise intensity, heat stress, workload and exposure duration on both noise induced TTS threshold shift and the recovery time. They found that recovery from TTS depends on "the severity of the hearing shift, individual susceptibility, and the type of exposure" and remarked that "if recovery is not complete before the next noise exposure, there is a possibility that some of the loss will become permanent". They found that recovery of TTS is very slow after either continuous exposure to noise for about 12 hours or intermittent exposures for long duration.

2.1.2.2 Permanent threshold shift (PTS)

Over-exposure to high intensities of noise, even for a short period of time, produces damage in the cochlea without recovery in hearing sensitivity; the threshold shifts are therefore permanent

and is referred to as a Permanent Threshold Shifts (PTS), (Syka, 2002, p.601). Continuous exposure to loud noise may induce progressive destruction of the IHCs and of the connecting afferent fibres that lead to irreversible PTS in excess of 60 dB (Dancer, 2004, p.7).

Bohne and Harding (1999, p. 2) described the pathogenesis of cochlear damage in detail. The longer the exposure to noise, the greater the loss of outer and inner hair cells, while the supporting cells, such as the outer and inner pillars, also sustain damage. Myelinated nerve fibres within the osseous spiral lamina begin to degenerate once the inner hair cells are damaged. The myelinated fibres are the peripheral processes of the spiral ganglion cells. Bohne and Clark (in Bohne & Harding, 1999, p. 2) termed the destruction of cochlear hair cells an outer hair cell "wipe-out". The spiral ganglion cells are subsequently progressively lost, including their central processes, which form the auditory portion of the eighth nerve. Once the spiral ganglia cells degenerate, there is corresponding degeneration in the central nervous system, including the cochlear nuclei, superior olive and inferior colliculus.

Dancer (2004, p.8) describes the consequences of noise trauma as cellular, functional, operational or financial:

- Cellular consequences: the result of noise trauma is cellular death. Two forms of cell death are described and are based on morphological and biochemical criteria. The cell death can be apoptotic or necrotic. Dancer (2004, p. 8) goes through great lengths in describing cellular consequences: "In apoptosis, chromatin condensation, cellular shrinkage and early preservation of plasma membrane integrity contrast with cytoplasmic disintegration and disorganized clumping of chromatin in necrosis. Apoptosis is a gene-directed self-destruction program, an active mode of cell death that results from the endogenous *de novo* protein synthesis. Apoptosis induces no spillage of cell contents and no inflammatory response".

Necrotic cell death is thought to be the result of more passive mechanisms triggered by extrinsic insults causing early disintegration of cells (Hu, 2009). According to Dancer (2004, p. 8) necrosis "induces spillage of cell contents and inflammatory response". The destruction of the hair cells may then spread progressively at some distance from the area of the first damage. The audio frequency range becomes progressively more affected by the PTS.

Past research on the impact of acoustic trauma focused mainly on physiological and morphological changes to the cochlear structures. Recent studies investigated the molecular mechanisms of hair cell death and found multiple modes of acoustic trauma. "Understanding how cochlear hair cells respond to acoustic overstimulation is pivotal for exploring protective strategies for reducing NIHL" (Hu, 2009).

- Functional consequences: with threshold shifts being either temporary or permanent, the frequency selectivity is decreased and recruitment and tinnitus can be present (Dancer, 2004, p.8)
- Operational consequences: PTS leads to a decrease in frequency selectivity and induces difficulties in the detection and localisation of sound. It further affects speech intelligibility in noisy environments.
- Financial consequences: Although Dancer (2004, p.8) described the financial consequences for soldiers the same will apply to workers in the mining industry. Withdrawing trained workers from certain specific jobs as a result of NIHL can not only have negative financial implications for both the mine and the individual worker but also have a negative effect on productivity.

2.1.2.3 Acoustic trauma

Acoustic trauma occurs when the ear is exposed to sudden high-intensity noise, such as an explosion. All structures of the hearing mechanism are damaged, thus causing immediate sudden hearing loss (Rosen, 2001, p. 2). It was found that a compound threshold shift can occur that suggests that the hearing loss has both temporary (conductive) and permanent components (sensory neural). This leads to a mixed type of loss where the ossicular chain is dislocated or damaged and/or the tympanic membrane is ruptured. The conductive element can, to a certain extent, be rectified with surgery. Should the temporary threshold shift not correct over time, the individual is left with a permanent threshold shift. Total hearing loss after acoustic trauma has also been recorded (Ginsburg & White 1994, p. 18).

2.1.3 Non–auditory effects of noise on hearing

Although Melnick (1996, p. 536) remarked that no conclusive evidence has been found that psychological effects other than hearing loss can be produced at sound levels known to be hazardous to hearing; recent studies indicated that negative psychological effects of noise are underestimated (Steenkamp, 2003, p. 91; WHO, 2003, p. 42). The adverse effects of hazardous noise on quality of work life and the strong relation between noise levels and accident rates have been reported (Steenkamp, 2001, p. 786), while the effects of noise on psychological factors such as productivity, production defects, fatalities, poor concentration, stress and cardiovascular problems are researched extensively (Ising & Kruppa, 2004, p. 1; Berger, 2001, p. 5).

Besides the primary known effects of noise on hearing ability there are also secondary effects that often tend to go unnoticed by researchers. These include disturbance in sleeping patterns, inability to concentrate and other psycho-physiological effects. It further affects mental

health, adding to cardiovascular problems, annoyance and it may interfere with intended activities (Crandell, Mills, & Gauthier, 2004, p. 176; WHO, 2003, p. 39).

2.2 Hearing conservation

Noise control engineering (NCE) should be regarded as the preferred approach to hearing conservation as it offers the greatest potential for reducing the risk of NIHL (Department of Minerals and Energy, RSA, 2003, p. 21). The principal purpose of any HCP is to protect the worker against cochlear damage caused by excessive noise in the workplace (Melnick, 1996, p. 548).

The South African mining industry is governed by the Code of Practice for the Measurement and Assessment of Occupational Noise for Hearing Conservation purposes as laid down by the South African Bureau of Standards (SANS 10083:2004). The code of practice stipulates standards for measurement and rating of working environments for conservation purposes and also the necessary HC measures to be applied. All workers exposed to 85 dB(A) time-weighted-average are to be included in a HCP. “Given the potential impact of NIHL on employers’ operations and finances, as well as on employees’ health, earning potential and quality of life, a HCP should be controlled and reviewed in accordance with the same management principles that employers apply to their business activities” (Department of Minerals and Energy, RSA, 2003, p. 27).

Hearing conservation is a very broad and complex field that entails much more than the mere use of HPDs. Noise control is a highly specialized field that requires the skills of acoustic engineers and occupational consultants. Although the *Noise Effects Handbook* of the National Association of Noise Control in the USA became available more than two decades ago (1981), the criteria suggested for addressing the noise problem are still relevant today. In this guide three basic elements of approaches to be singled out are the source of the generated noise, the transmission path of the unwanted sound (noise) and the receiver or worker (National Association of Noise Control 1981, p. 24).

The measurement and assessment of occupational noise for hearing conservation purposes are described in SANS 10083, (2004). The standard covers the measurement and rating of a working environment for hearing conservation purposes, the physical demarcation of an area where hearing conservation measures have to be applied and medical surveillance. These regulations are applicable to an employer or self-employed person who carries out work that may expose any person at that workplace to noise at or above the noise-rating limit of 85 dB(A). According to these regulations a HCP should include the elements discussed in sections

2.3.1 - 2.3.7 below.

2.2.1 Assessment of potential noise exposure

The assessment of potential noise exposure is done for both new installations and existing installations. This assessment determines the extent to which a worker is exposed for a 8 hour work shift (*LA*eq, 8h) and whether a hazardous noise source exists. It further determines if an analysis of the noise is required. Once the hazards has been located and analyzed, the employer should initiate noise control engineering or administrative procedures to either eradicate or control the noise. The effectiveness of the measures taken to reduce noise exposure should be checked. If it is not possible to control noise levels to below 85 dB(A), demarcations of noise zones in accordance with Clause 7 of the SANS 10083 (2004, p. 11) should be done. The noise exposure results will be used as a guide in the selection of appropriate hearing protection equipment.

2.2.2 Demarcation of noise zones

In any workplace where exposure to noise is at or above the noise-rating limit (85 dB(A)), that workplace will be zoned as a noise zone. The workplace will be clearly demarcated and identified by a notice indicating that the relevant area is a noise zone and that hearing protective equipment must be worn. The appropriate mandatory symbolic safety sign for hearing protection (see SANS 1186-1 2011 and Figure B.1) should be in a conspicuous place at all entrances to and exits from such areas. No person enters or remains in these areas unless hearing protection devices are worn (SANS, 10083: 2004, p. 14).

2.2.3 Medical surveillance

“All employees who are exposed to noise at and above the noise rating limit for hearing conservation purposes or who are required to enter noise zones (or both), should undergo audiometric examination in accordance with Clause 15 to Clause 21, inclusive, in view of the fact that hearing protection equipment does not provide adequate protection under all circumstances**”** (SANS, 10083: 2004, p. 22).

According to the legislation, routine audiometric tests and medical examinations are compulsory and should take place annually. It consists of a baseline and periodic audiograms conducted according to SANS 10083 (2004, p. 23). For the purpose of obtaining a baseline audiometric test result, two screening tests on an employee have to be conducted on the same day. The results of the two tests must not differ from each other by more than 10 dB at any of the tested frequencies. The frequencies to be measured are; 500 Hz, 1000Hz, 2000Hz, 3000 Hz and 4000 Hz (air conduction). If the results are considered to be valid the better of the two

audiograms (that is, the audiogram with the lowest calculated permanent loss of hearing) is considered to be the employee's baseline audiogram. The values at each frequency will be summed to obtain the permanent loss of hearing (PLH) percentage. The percentage loss of hearing will be calculated according to the guidelines stipulated by the Department of Labour Compensation for Occupational Injuries and Disease Act, 1993 (Act No.130 of 1993). The established baseline audiogram will be used as a basis against which all subsequent audiometric results are to be compared in determining future compensable hearing loss. Should, after repeated testing, inconsistencies be found in audiometric responses, the employee must be referred to an audiologist for the purpose of establishing a valid baseline audiogram. When it is not possible for the audiologist to obtain a baseline audiogram as required in 17.3 of SANS 10083, (2004, p. 26), other techniques such as a speech reception threshold may be acceptable for baseline purposes. If, during routine screening, a possible shift of more than 10% in the permanent loss of hearing from the baseline results is found, the employee should be regarded as a possible candidate for compensable hearing loss in terms of the relevant legislation and will be referred for diagnostic audiology. PLH is calculated using the better results of two diagnostic audiograms. Should the results found to be inconsistent, a third test must be performed. The test will be delayed for six months should inconsistencies still be found. If inconsistencies still exist after the six month period, a referral to an ear, nose and throat specialist should be made in order to determine the hearing loss. A PLH calculation can be made if the audiograms obtained are consistent and valid. The information of the PLH will be submitted to the Compensation Commissioner, Mutual Association or employer for further consideration for possible compensation. Six-monthly monitoring audiograms are suggested to be performed on workers where the noise exposure equals or exceed an 8 hour rating level of 105 dB(A), (SANS 10083: 2004, p. 23). An exit audiogram should be performed on each employee at the end of the employment or contract, or when he/she is permanently transferred out of the noise area. The employee shall be given a copy of the baseline audiogram, the results of the exit audiogram and the relevant personal and medical records.

2.2.4 Information and training

Before any employee is exposed or may be exposed to noise at or above the noise rating limit of 85 dB(A) it will be insured that the employee is adequately and comprehensively trained on both the practical aspects and the applicable theoretical knowledge of noise exposure. Guild, Ehrlich, Johnston and Ross (2001, p. 199) suggested that the educational component should cover the potential risks to health and safety caused by exposure to noise, the effects of noise on

hearing, the correct use, maintenance and limitations of HPDs and the purpose of the surveillance. Refresher training on the above aspects shall be provided at intervals of two years or at intervals as recommended by the health and safety committee (SANS 10083: 2004, p. 23).

2.2.5 Hearing protection equipment

Hearing protection equipment that complies with the SANS 1451-1 (2008), SANS 1451-2 (2008) or SANS 1451-3 (2008), should be provided free of charge to employees working in a noise zone. Employees should be offered a reasonable range of suitable hearing protection devices from which to choose. Individual fitment of HPDs is to be performed by an occupational health practitioner or other appropriately competent person/s, as part of the risk-based medical examination. It is suggested that monitoring of the condition of HPDs should be performed at quarterly intervals by an occupational health practitioner or other appropriately competent persons. According to the South African Department of Minerals and Energy (2003, p.5) "monitoring means the repetitive and continued observation, measurement, and evaluation of health and/or environmental or technical data, according to prearranged schedules, using nationally or internationally acceptable methodologies". HPDs supplied to workers will be new and unused, unless it is earmuffs that have been properly cleaned and, where appropriate, sterilized and stored in a suitable container. "Disposable hearing protection equipment (such as certain types of ear plugs) shall be replaced when required, taking hygiene and the general condition thereof into consideration" (SANS 10083: 2004, p. 22).

Hearing protectors usually are of three different types: first, the insert-type: These are earplugs that are placed in the external auditory meatus and seal against the walls of the said meatus; the second type is known as muff-type devices that seal against the head around the pinna, or concha; and third, devices described as seated protectors that provide an acoustic seal right at the entrance to the external ear canal (referred to as canal caps). Another type of HPD is described as an acoustic helmet that provide hearing protection; additional variants employing electronic circuitry are available as well (Byrne, Davis, Shaw, Specht & Holland, 2011, p. 86). Since a wide range of available hearing protectors are capable of dealing with a variety of work situations it is suggested that, in selecting a HPD, the specific job situation of the user should be kept in mind. The following factors need to be taken in to account:

- SANS certification mark
- Sound attenuation requirements
- Wearer's comfort
- Working environment and activity

- Medical disorders
- Compatibility with other headgear such as helmets, spectacles, etc.

Examples of the major types and styles of HPDs can be seen in Figure 1.

Figure 1. Examples of the major types and styles of hearing protectors: ***(a)*** *Circum-aural earmuffs (Elvex, 2008); (b) Bilsom Leightning T1 Cap-Mount Earmuffs (Bacou-Dalloz, 2011) (c) Active noise reductor earmuff (Elvex, 2008) (d) The USMC Acoustic helmet (Henry, Faughn, & Mermagen, 2008.p. 9); (e) Communication earmuffs (Peltor, 2008);* ***(f)*** *Disposable foam earplugs (The 3M Company 2010); (g) Premoulded earplugs E-A-R Ultrafit (The 3M Company 2010); (h) Reusable earplugs (Elvex, 2008) (i) Banded earplugs (elvex.com, 2008); (j) Custom moulded earplugs (Noise Clipper ®, 2008)*

- **Earmuffs**

This circum-aural HPD (Figure 1(a, b & c) encloses or surrounds the ear and is sealed to the head with soft cushions that can be filled with foam or liquid. The cups are lined with sound-absorbing material and are connected with a headband (also referred to as a tension band) made of steel or plastic (Elvex, 2008). Variations on conventional earmuffs are found and are referred to as special types. Five types of protectors are described in this category:

- The helmet-mounted earmuff where two individual cups are attached to arms that are fixed to a safety helmet and are adjustable to be positioned over the ears when required (Bacou-Dalloz, 2011) ;
- An active noise reduction protector that makes use of electro-acoustic devices that partially cancels incoming sound to optimise protection (Elvex, 2008);
- Level-dependent protectors that are designed to provide increased protection as the sound level increases (Elvex, 2008);
- Communication earmuffs that allow communication of working signals, alarms, messages or entertainment programmes making use of a wired or aerial system (Peltor, 2008);
- Acoustic helmets that cover a large part of the head and the ears. This can reduce the effect of bone conduction via the skull to the cochlea (Henry et al., 2008).

The greatest limitation of earmuffs is found in the design. Research established that earmuff headband tension is reduced with use and stretching, causing the attenuation capabilities to deteriorate, most often without the user's awareness (Brueck, 2009, p. 44). Because conventional earmuffs have limited use in conjunction with safety headgear such as safety goggles, oxygen masks and safety helmets, variations are available that consist of band connectors described variously as headbands, neckbands, chin bands and universal bands. Although laboratory tests found the attenuation capabilities of earmuffs to be adequate, research conducted by Brueck (2009, p. 42) indicated that real world attenuation effectiveness is reduced when used with other personnel protective devices. It was found that some safety goggles used in conjunction with earmuffs reduced attenuation effectiveness by up to 10 dB. Further limitations of earmuffs (depending on the type) are over-attenuation that leads to auditory isolation. The results of a study conducted by Abel, Sass-Kortsak and Kielar (2002, p. 6) on one specific type of HPD, they demonstrated that the protection afforded by certain cap-mounted earmuff (attached to a standard hard hat for the prevention of NIHL) was compromised when the

device was worn in combination with other safety gear in close proximity. They found a decrease in attenuation effectiveness that was greatest at the lowest frequencies tested, that is, 250 Hz and 500 Hz. It was further established that the fit of the muff itself determined the attenuation outcome and was compromised by the hard hat attachment.

Earplugs

Earplugs or intra-aural HPDs are inserted into the meatus or in the concha. This is done to seal off the entrance to the meatus. Two types of earplugs are available: disposable, intended for one fitting only and reusable, intended for more than one fitting.

Variations found in earplugs are:

- Pre-moulded earplugs that can readily be inserted into the meatus without prior shaping and are usually made of soft forms of glass down, silicone, rubber, or plastic;
- User formable earplugs that are made of compressible materials that the user moulds him/herself before insertion into the meatus. These earplugs often expand, forming a seal in the meatus;
- Banded earplugs are suspended on a headband to hold the ear caps in place. Banded earplugs, or semi-aural devices, are placed at the entrance of the meatus where it is intended to cause a seal. The headband can fit behind the head or under the chin, allowing greater versatility so that eyeglasses, safety glasses, or other items of safety equipment that a worker may be wearing would not compromise a proper fit. The design of these HPDs causes it to be used for only short periods of time because they become uncomfortable to wear, due to the force exerted by the cap on the ear canal entrance (Christian, 2000, p. 13)

5% inserted: 0 dB attenuation	50% inserted: 6 dB attenuation	75% inserted: 16 dB attenuation	100% inserted: 22 dB attenuation

Figure 2. Noise reduction ratings and earplug insertion depth (McKinley & Bjorn, 2006, p.5).

The attenuation of foam earplugs depends significantly on insertion depth. In Figure 2 above, McKinley and Bjorn (2006, p. 5) demonstrate how insertion depth affects the attenuation effectiveness. A good fit is sometimes difficult or impossible to achieve due to variation in the size and shape of the wearer's ear canal or ability to mould the device sufficiently for deep insertion (Christian, 2000, p. 11). Earplugs have an advantage over earmuffs and canal caps in that they attenuate low-frequency noise more effectively and do not affect the user's ability to wear eyeglasses and other personal protection equipment. While earplugs are often more comfortable in hot and humid environments than earmuffs, they are not suited for dirty environments unless replaced regularly or hygienic methods implemented.

Custom-moulded earplugs (CHPDs) are made by taking an ear impression of the user's ear canal first, and by then producing an earplug that matches the impressions. A filtering device is inserted into an inner bore of the CHPD and can be adjusted for different attenuation levels. In a study conducted by Neitzel, Somers and Seixas (2006, p. 679) it was found that CHPDs achieved a higher mean percentage of labelled attenuation than did the foam earplugs, and that the CHPDs had higher overall acceptance among workers than conventional HPDs.

The CHPD used at the Impala Platinum mine where the research was conducted, that is, the Noise Clipper®, was designed and manufactured in South Africa. Ear canal impressions are taken by qualified audiometricians employed by the Noise Clipper® Company. An otostop is placed into the ear canal up to the second bend of the auditory meatus. A mixing syringe (Dreve) is used to inject impression material into the ear canal. The materials used for impression taking are supplied by Dreve Otoplastik GMBH and consist of a double cartridge (24 ml each) Otoform A-Soft impression material with a shore rating of 40. The earplug, also referred to as an otoplastic, is manufactured using a UV-polymerization technique with materials obtained from Egger Otoplastik and Labortechnik GmbH. The material consists of a mixture of acrylic/metacrylic resin, silicium dioxide and auxiliary matters and pigments (Egger, 2011, p. 2). The otoplastic is fitted with a filtering device (Figure 4) into an inner bore (a canal drilled into the otoplastic body). The final product (the otoplastic) is said to be manufactured using hypoallergenic material. During the casting process the user's name, date of manufacture and left ear/right ear markings are embedded in the transparent otoplastic body. For the fitment of the CHPD, audiometrist of the Noise Clipper® Company will conduct a seal test on every otoplastic fitted and make sure that the

worker understands the fitting and maintenance processes needed to use the Noise Clipper® CHPD on a daily basis. Should the otoplastic be found to be leaking or perceived by the worker as uncomfortable, new impressions will be taken and the otoplastic will be remade and refitted using the same criteria as described above.

Figure 3. The Noise Clipper® CHPD (Noise Clipper®, 2007)

The worker's names, R for right ear and L for left ear and date of manufacturing that is embedded in the body of the otoplastic can be seen in Figure 3. The two otoplastics (right ear and left ear) are connected with a flame retarding non-shaving cord (not presented in Figure 3). The Noise Clipper® CHPD makes use of a filtering device that can be adjusted according to the client's attenuation requirements. The filter design is visualized in Figure 4.

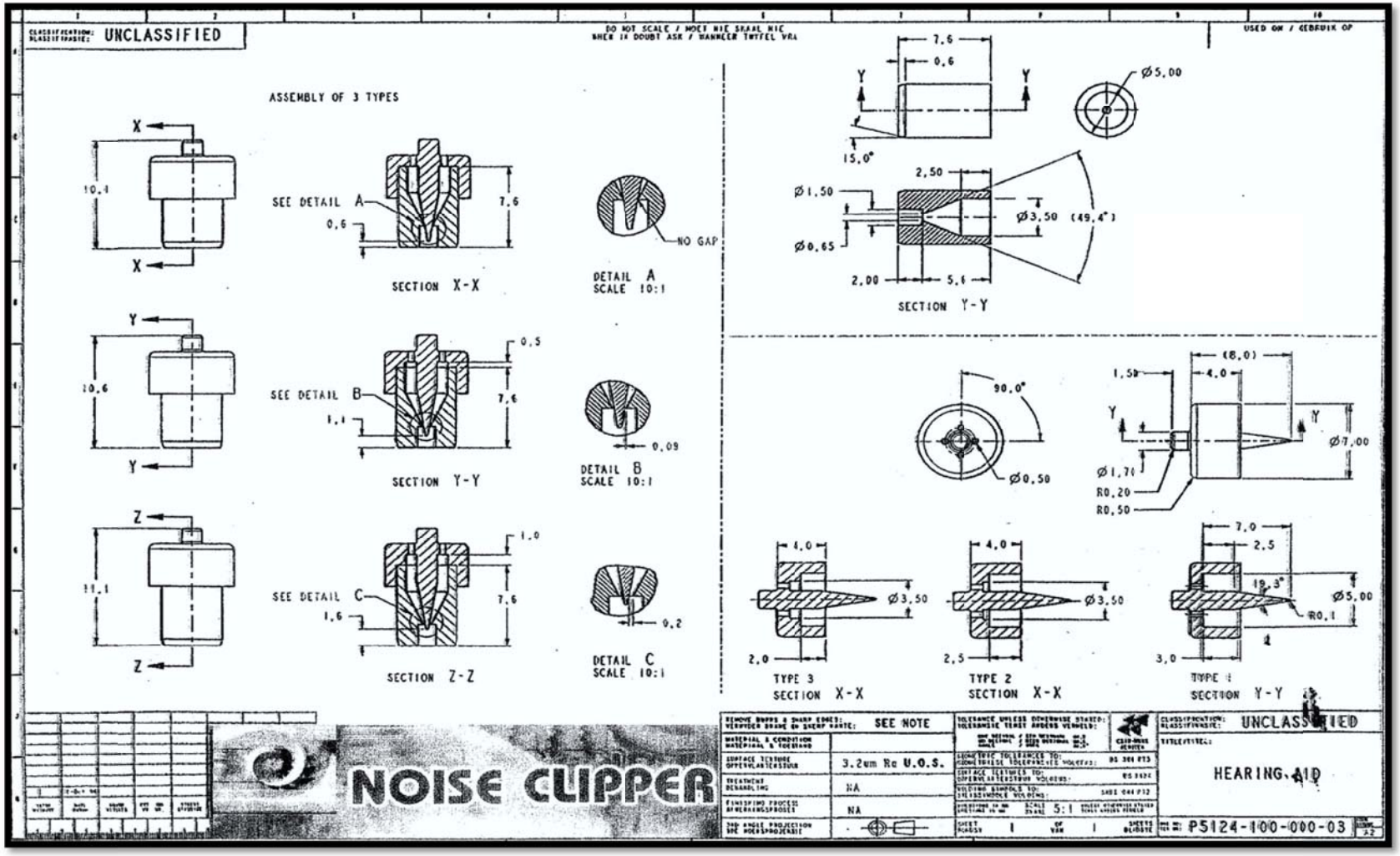

Figure 4. The Noise Clipper® CHPD filter design (Noise Clipper®, 2007)

The Noise Clipper® CHPD is fitted with a filtering device that can be adjusted for different attenuation levels. Three assembly types resulting in three attenuation levels are visualized in Figure 4 Section X-X, Detail A (no gap) depicts a closed filter setting for optimal attenuation while Section Z-Z, Detail C is a drawing for a lower attenuation (larger gap) filter setting. These gaps create a two-section low-pass filter that is designed to provide attenuation that dramatically increases with frequency, yielding negligible attenuation below 1000 Hz but up to about 35 dB at 8000 Hz. The smaller the gap the more restricted the air flow through the inner bore in the otoplastic leading to greater attenuation of the device (Noise Clipper® Manual 2007, p.6).

The Noise Clipper® CHPD complies with the requirements of the SANS 1451-2 Hearing protectors Part 2: Ear-plugs and is approved by the SANS with their verification mark. The REAT attenuation values, can be seen in Table 1, indicating sufficient attenuation of sound pressure levels in accordance with the specifications of the SANS 1451 Part 2: Ear-plugs.

Table 1 Real Ear Attenuation Values (REAT), Standard Deviations and Minimum SANS 1451 Pt 2:Ear-plugs, Requirements of the Noise Clipper® CHPD

Minimum frequency in HZ	Noise attenuation of Noise Clipper®	Standard deviation	Required minimum
125 Hz	23.5dB	6.2	18dB
250 Hz	24.3 dB	6.3	16dB
500 Hz	26.4 dB	9.2	19dB
1000 Hz	26.1 dB	8.2	23dB
2000 Hz	30.7 dB	6.7	26dB
4000 Hz	39.1 dB	5.3	30dB
8000 Hz	38.4 dB	6.8	30dB

In Table 1 the mean attenuation and standard deviation (dB) values at given centre frequencies (Hz) are given. The real ear attenuation values (Mean1-SD) are calculated by de-rating the mean values by one standard deviation point (Neitzel et al., 2006, p. 6). The mean-1 SD value obtained for the measured centre frequencies indicate the assumed protection values (APV) afforded by the Noise Clipper® CHPD. Table 1 shows that attenuation is highest for the frequencies normally associated with noise-induced damage (2000 Hz to 8000 Hz).

2.2.6 Maintenance and control measures

The Occupational Health and Safety Act (1993 , p.10) stipulates that anything that is provided for the benefit of employees in compliance with their duties shall be fully and properly used and effectively maintained in good working order and in good repair and cleanliness.

2.2.7 Record keeping

In SANS 10083: 2004, (p. 33) it is suggested that the employer will ensure keeping of the following records (as applicable) are kept:

- a baseline audiogram
- subsequent annual periodic screening audiometry results
- exit audiometry
- diagnostic baseline results (following referral to an audiologist)
- results from the appropriate medical practitioner (following referral)
- records and correspondence pertaining to claims submitted to the Compensation Commissioner
- records of training and information (including attendance lists) given to employees regarding hearing conservation in accordance with the relevant legislation.

All records of training given to an employee shall be kept for as long as the employee remains employed in the workplace where he/she is exposed to noise (Occupational Health and Safety Act, *1993,* p. 9). All the records described above will be kept of every employee for a minimum period of 40 years.

A study conducted by Edwards, Dekker, Franz, van Dyk and Banyini (2007) on the profiles of noise exposure levels in South African mining industry revealed that the mean exposure levels ranged from 63.9 dB (A) to 113.5 dB (A) and that approximately 73.2 percent of miners are exposed to noise levels above the legislated action level of 85 dB (A).

As a result of these findings the Mines Health and Safety Council have established milestones for the limiting of occupational noise exposure and the elimination of NIHL. The fist milestone is that "after December 2008, the HCPs implemented by industry must ensure that there is no deterioration in hearing greater than 10 % between occupational exposed individuals. By December 2013 the total noise emitted by all equipment installed in any workplace must not exceed a SPL of 110 dB(A) at any location in that workplace" (Hermanus, 2007, p. 535).

The National Technical Committee of the South African Bureau of Standards which is responsible for the standards concerning hearing protection devices, has accepted the text of the South African Standard Code of Practice, titled *Hearing Protectors; Recommendations for selection, use, care and maintenance; Guidance document* (*SANS EN 352-23*) as a suitable standard for South Africa. This standard is used to assist in the supply, selection, and use of hearing protectors and to encourage the use of effective criteria in the selection process. It

places great emphasis on the importance of comfort and acceptance of selected hearing protection devices. Franz (2002, p. 65) cautions that employers should provide HPDs that comply with standards stipulated by SANS *10083*, (2004). The standards on HPDs: *South African National Standard 1451-1*, (2008) (earmuffs), II: 2008 (earplugs) or III: 2008 (helmet-mounted earmuffs). The literature search and specifically the findings of Bloom (1997, p. 24); Chandler (2001, p. 2); Hager (2002, p. 2); Hiselius and Berg (1999, p. 1.); Park and Casali (1991, p. 152); Steenkamp (2003, p. 92) and Vinck (2007, p. 10) provided a firm background concerning the problems encountered with conventional HPDs in protecting the human ear against NIHL. It appears that conventional measures to conserve hearing remain problematic despite all the programs and recommendations found in legislation and literature. Conventional HPDs are often misused and abused in favor of comfort, thereby causing ineffective hearing protection (Hager, 2002, p. 3; Hiselius & Berg, 1999, p. 2; Park & Casali, 1991, p. 152). An important requirement in the use of any HPD is that the worker will use the device willingly and consistently (Hiselius & Berg, 1999, p. 2). Besides the attenuation properties of HPDs one of the most important factors for consistent use is that of comfort (Park & Casali, 1991, p. 152).

The protection provided by a HPD depends not only on its attenuation properties but also on the time it is consistently and effectively worn (Arezes & Miguel, 2005, p. 1; Neitzel & Seixas, 2005, p. 227). The effectiveness of HPDs are reduced if the user removes it for even short periods in noisy environments (Arezes & Miguel, 2002, p. 533; Davis & Sieber, 1998, p. 721; Vinck, 2007, p. 19). This can be illustrated by the equation: $R= 10 \times \log \{100/ [100-p (1-10^{n} -n/10)]\}$ where R represents the real-world attenuation of the HPD with nominal attenuation, *N*, used for time, *p*, (%) of total shift. Should a HPD be removed for only 10% of the time during a work shift (48 minutes of an eight hour shift), the attenuation afforded by the HPD, with a nominal attenuation of 30 dB, would be less than 10 dB (Arezes & Miguel, 2002, p. 533). The effect of HPD removal on overall attenuation effectiveness is illustrated in Figure 5 (National Institute of Occupational Safety and Health, 1996).

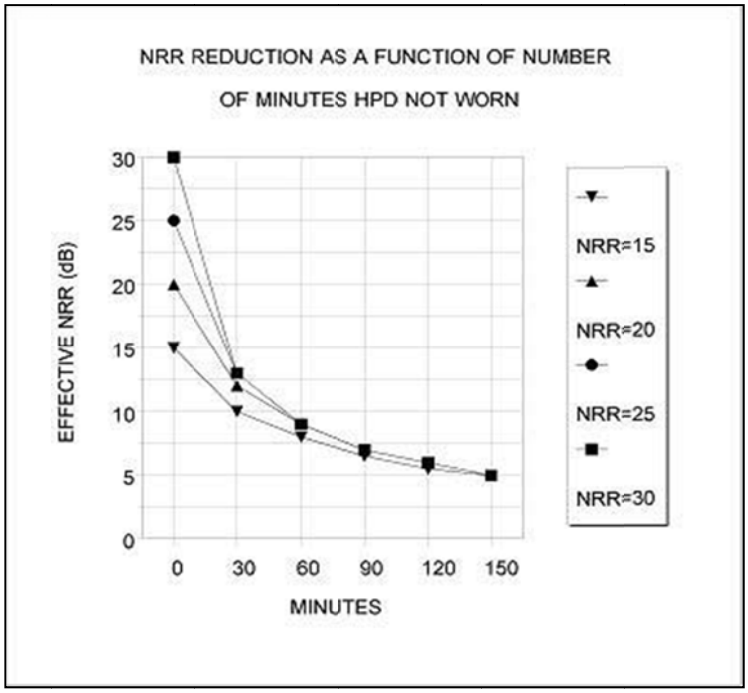

Figure 5. Noise reduction rating as a function of number of minutes a HPD is not worn (National Institute of Occupational Safety and Health, 1996)

The time corrected NRR is demonstrated in Figure 5. The percentage time during which the HPD is not worn (during an eight hour work shift) will have a detrimental effect on its attenuation effectiveness. If a HPD has a NRR of 30 dB(A), it would be 100% effective if worn for a full eight hour work shift. If, for example, the HPD is removed for 30 minutes the NRR will fall below 10 dB(A). It is therefore extremely important that the worker should use the protective device willingly and consistently (Hiselius & Berg, 1999, p. 2; Park & Casali, 1991, p. 152).

The acoustical attenuation efficiency and the comfort afforded by HPDs will affect the user's acceptance and consistent use in noisy work environments. Over attenuation and discomfort will lead to users not using the HPD for full eight hour work shifts. Arezes and Miguel (2002, p. 532) remarked that the acoustic attenuation properties are not the only characteristics of a HPD that protect a worker from hearing damage due to hazardous industrial noise. Other important ergonomic features should also be taken into account such as comfort, need for verbal communication (elimination of over protection), durability, signal detection, compatibility with other safety equipment, maintenance and cost.

The position statement of the American Audiological Association (AAA) refers to the four-C's when describing HPDs: "comfort, convenience, cost and communication" (American

Academy of Audiology 2003, p. 7). Besides the attenuation ability of HPDs, the single most important issue identified as being problematic throughout literature is that of comfort (Arezes & Miguel, 2002, p. 532; Bloom, 1997, p. 26; Gibson, 1999, p. 1; Morata, Fiorini, Fischer, Krieg, Gozzoli, & Colacioppo, 2001, p. 25-32; Steenkamp, 2001, p. 789). It is widely believed that comfort is a key factor determining whether workers will wear a HPD or not (Casali, Lam & Epps, 1987, p. 18). In the mining industry, HPDs are supposed to be worn for an entire shift and it is therefore critical that the HPDs used are comfortable if they are to be effective. The research findings and comments made by Bennett (1998, p. 6), Bloom (1997, p. 24); Neitzel et al. (2006, p. 679); Steenkamp (2001, p. 792) and Vinck (2007, p. 21), suggested that the implementation of a CHPD might address some of the problems normally associated with conventional HPDs and has a bigger role as catalyst for a successful HCPs. The results of a study done by Neitzel et al. (2006, p. 6) indicated that CHPDs had the highest average scores concerning comfort, perceived protection and overall rating opposed to conventional HPDs (earplugs). Steenkamp (2001, p. 790) argued that CHPDs will be more durable, cost effective, and comfortable than conventional HPDs. To ensure comfort a CHPD should not only be custom-made but also custom-fitted (Steenkamp, 2001, p. 789). Shanks and Patel (2009, p. 28) evaluated five different CHPDs and found that three out of the five did not match the manufacturers claimed attenuation levels it had lower attenuation levels than claimed. They observed that the quality of an impression is directly related to the comfort of the final product. An additional limitation of CHPDs is that individuals that take impressions needs to have a certain level of skill, training and experience (Shanks & Patel, 2009, p. 30). Manufacturers of CHPDs “often claim that users can achieve a superior repeatable fit compared with other forms of hearing protection, giving the user the level of protection claimed by the manufacturer ” though no evidence of these claims could be found in the study data (Shanks & Patel, 2009, p. 28).

The present study will not evaluate or suggest measures for the first defense, namely engineering or administrative controls, but will evaluate a single CHPD.

2.3 Measurement of the effectiveness of hearing protection devices

Current assessment methods can be separated into three main categories: objective test methods or physical methods that use a manikin or an acoustic test fixture, semi-objective methods such as the MIRE technique that uses human subjects in a passive role and, subjective or psychophysical methods such as the REAT technique where measurements are based on subjective judgment in carefully controlled laboratory environments (Berger, 2005, p.53).

The psychophysical method of attenuation measurements, referred to as the REAT, is a subjective standardized method used to compare performance data of HPDs obtained in different laboratory locations and conducted under similar conditions for the purposes of HPD attenuation comparison between devices. The REAT protocol is conducted in carefully controlled laboratory situations performed by trained experimenters on informed subjects so that attenuation measurements (repeatability of test) can be consistently reproduced. The data may be used for rank ordering and selection of different HPDs and for the evaluation of the design and construction features that affect the device's performance. The REAT protocol yields data that are collected close to the threshold of hearing. The attenuation values obtained with this protocol are intended to be representative of attenuation values of HPDs at intensities higher than 85 dB (SPL) (ISO, 1990, p. 1).

2.3.1 The REAT test protocol for measuring sound attenuation

The test environment, background noise control, test signals and signal distortion are specified in great detail in the ISO 4869-1 standard. Defining how the subjects will be selected, trained, coached and fitted with the HPDs is by far the dominant factors influencing the results (Berger, 2005, p. 3).

2.3.1.1 The REAT test procedure

The REAT test protocol is a measurement of the shift in thresholds (insertion loss) between an occluded and un-occluded ear for a group of subjects. The thresholds are measured via automatic audiometric testing using the Bekesy audiometric procedure with 1/3 octave band pulsed sound stimuli delivered in seven frequency bands centred at 250, 500, 1000, 2000, 4000, 6000 and 8000 Hz (Neitzel et al., 2006, p. 3). "Controlling the background noise in the test environment and the distortion in the test signals are the most critical technical aspects of the procedure" (Berger 2005, p. 3). According to Berger (2005, p. 3) the attenuation results obtained from the REAT test protocol has shown to be predictive of attenuation over a wide range of sound levels, although the measurements are made within 50 to 60 dB of the threshold of hearing. The REAT test protocol is the only attenuation measurement that accounts for all the relevant sound paths to the protected ears, including the bone-conduction pathways. The one known artefact of the procedure is the amplification of the physiological noise in the protected condition by the occlusion effect. This masks the thresholds and therefore spuriously increases the difference between the open and protected thresholds. This effect is limited to frequencies below 500 Hz and to magnitudes of up to about 6 dB (Berger, 2005, p. 3).

The REAT attenuation values are calculated by de-rating the mean values by two

standard deviation points (Neitzel et al., 2006, p. 6). The mean-2 SD values obtained for the measured centre frequencies indicate the attenuation values afforded by a HPD.

Berger (2000, p. 1) compared the laboratory versus real-world attenuation differences of sixteen HPDs. Not one of the HPDs real-world attenuation performances correlated with the manufacturers' claimed NRRs. With these grave differences, the existing methods used for measuring HPDs attenuation are questionable and the success of predicting a HPDs performance with a great degree of certainty appears to be minimal (Durkt, 1998, p. 19). Berger et al., (1996, p. 368) compared the laboratory test results of HPDs with 22 real-world studies and found overestimations of attenuation of between 140% and 2000%. Existing approaches on attenuation measurements are highly criticized throughout literature (Berger, 2000, p. 7; Hager, 2002, p. 1; Neitzel & Seixas, 2005, p. 227; Neitzel et al., 2006, p. 2; Vinck, 2007, p. 19). The greatest criticism on the existing methods of attenuation measurements is the test itself (Vinck, 2007, p. 22).

A task group of the North American Treaty Organization, Research and Technology (North American Treaty Organization, 2010, p. 68), went to great lengths to describe the different methods for attenuation measurement. The first to be discussed by the task group was the REAT test protocol. They described this test protocol to be a measurement of the sound pressure level at the cochlea. When assessing the attenuation of HPDs, where bone conducted noise is likely to be a consideration, the REAT test is described as being the preferred protocol. The task group cautions that:

- The REAT test protocol is based on the subjective opinion of the test subjects and may consequently result in a wide variance in the attenuation measured across subjects.
- The measurement does not provide attenuation information of the frequencies between the 1/3-octave bands of noise, because the standard method only presents 10 centre frequencies, generally spaced about an octave apart.
- Over-estimation of the occluded threshold at 63 Hz and 125 Hz may occur due to physiological noise masking the test frequencies.
- The requirement of a HPD is that it should be effective at high noise levels. With the REAT test protocol the HPD is only tested at threshold levels and not in a high noise environment.
- The procedure for performing the REAT test protocol is lengthy and requires subjects to have a good attention span (North American Treaty Organization, 2010, p. 68).

2.3.2 The MIRE test protocol for the objective assessment of sound attenuation.

In the present study the term field–MIRE will be used when referring to MIRE measurement and will be abbreviated F-MIRE as it will be applied in occupational settings (Berger, 2007, p.2). ISO 11904-1(1990) described measurements carried out (MIRE) using miniature or probe microphones inserted in the ears of human while ISO 11904-2 (2004) describes measurements carried out using a manikin equipped with ear simulators including microphones (manikin technique). Only ISO 11904-1 (1990) will be discussed in this study regarding its specifications for a basic framework for the measurement of sound emission from sound sources placed close to the ear. The measurements are done using miniature or probe microphones inserted in the meatus of human subjects. The measured values are converted into free-field or diffuse-field levels. The results are then given as free-field related or diffuse-field related equivalent continuous A-weighted sound pressure levels.

The first part of the standard (ISO 11904-1, 1999) pertains to the basic setup requirements for the MIRE test protocol. Some of the aspects addressed in the first part are details on the reference microphone; calibration; filter selections; description of the test subjects; the use of the ear canal microphones; the choice of ear canal measurement position and safety aspects to be considered during the measurements. As described in part 5.3 of ISO 11904-1 “the calibration of the microphones and the measuring equipment shall be suitably checked. For the reference field microphone, this shall be done using an acoustic calibrator complying with the requirements for class 1 of IEC 60942”. The MIRE test protocol consists of a dual-element microphone that simultaneously measures the sound at the outside of the HPD and the sound behind the HPD in the ear canal after having passed through the HPD. The attenuation of noise in this protocol (the difference between the two measures) is referred to as noise reduction (NR).

Some of the advantages of the MIRE test protocol are that measurements are conducted in elevated noise levels (high load) and the results are not contaminated by physiological noise as is found with the REAT method (Vinck, 2007, p. 20). Other advantages of the MIRE method are that the measurements are much quicker to conduct and may account for individual differences in the fit of the HPD (De Muynck, 2007, p. 227). Some of the major disadvantages of the MIRE method as described by Lancaster and Casali (2004, p. 7) are:

- It does not account for true bone conduction effects that can lead to overestimation of mid frequency attenuation.
- Internal microphone placing can affect the seal for the need of connecting wires running underneath the ear tips.

- Seeing that the test is conducted under high loads on the human ear (high intensity ambient noise levels), it is unprotected during the initial stage of the test.

Vinck (2007, p. 16) argued that bone conduction is not a factor to be taken into account during REAT measurements because the tests are conducted under laminar/peri-laminar conditions (at threshold) and that bone conduction will only be a factor at thresholds above 40 dB to 60 dB. According Berger (2005, p. 4) one of the principal concerns regarding the MIRE measurement protocol is that it does not capture all the sound pathways in the same way as does the REAT measurement. "For real ears, the response to an incoming sound wave may be through vibration of the eardrum or by direct excitation of the cochlea via sound that stimulates the bone- and tissue-conduction pathways" (Berger, 2005, p. 4). This causes the results of the MIRE measurement to be "spuriously high above 1000 Hz, since in that frequency range the attenuation of an HPD in real ears can often be great enough to be influenced (i.e. limited) by bone-conduction transmission" (Berger, 2005, p. 4). This is relevant especially in the mining industry where workers are exposed to levels above 85 dBA. Probe placed microphones inserted into a second canal of the body of a CHPD will not affect the seal. The risk of hearing damage is reduced since the HPD is placed in the ear for sound field and noise reduction evaluations (both the monitor microphones are placed in the probe).

2.4 The biological threshold (BT) for temporary threshold shift (TTS)

Pioneering research conducted by Mills and Going (1982, p 120) found that for each centre frequency the human ear responds in a different way at different sound levels. For example, they indicated that the BT (critical levels) centred at 4000 Hz is 74 dB SPL, 78 dB SPL for 2000 Hz, 82 dB SPL for 1000 Hz and 500 Hz (Mills and Going, 1982, p. 119).). The critical levels for TTS define the so-called "safe levels of noise or acoustic injury thresholds" (Mills & Going, 1982, p. 120). Noise levels above the critical levels will lead to a permanent threshold shift (De Muynck, 2007, p. 221). They found that TTS increases during the first eight to 12 hours of noise exposure and eventually reaches a plateau or asymptote. The TTS thresholds at asymptotic increases with 1.7 dB for every decibel increase in noise level above the critical level and are dependent upon frequency (Mills & Going, 1982, p. 120). These critical levels are of concern to the researcher, but are often disregarded in hearing conservation research. Data captured from laboratory and field studies indicate that a risk of hearing damage is present when noise levels are above 75 to 80 dB(A) (Mills & Going, 1982, p. 120). The effects of noise on auditory sensitivity, psychophysical tuning curves and suppression are demonstrated in Figure 6.

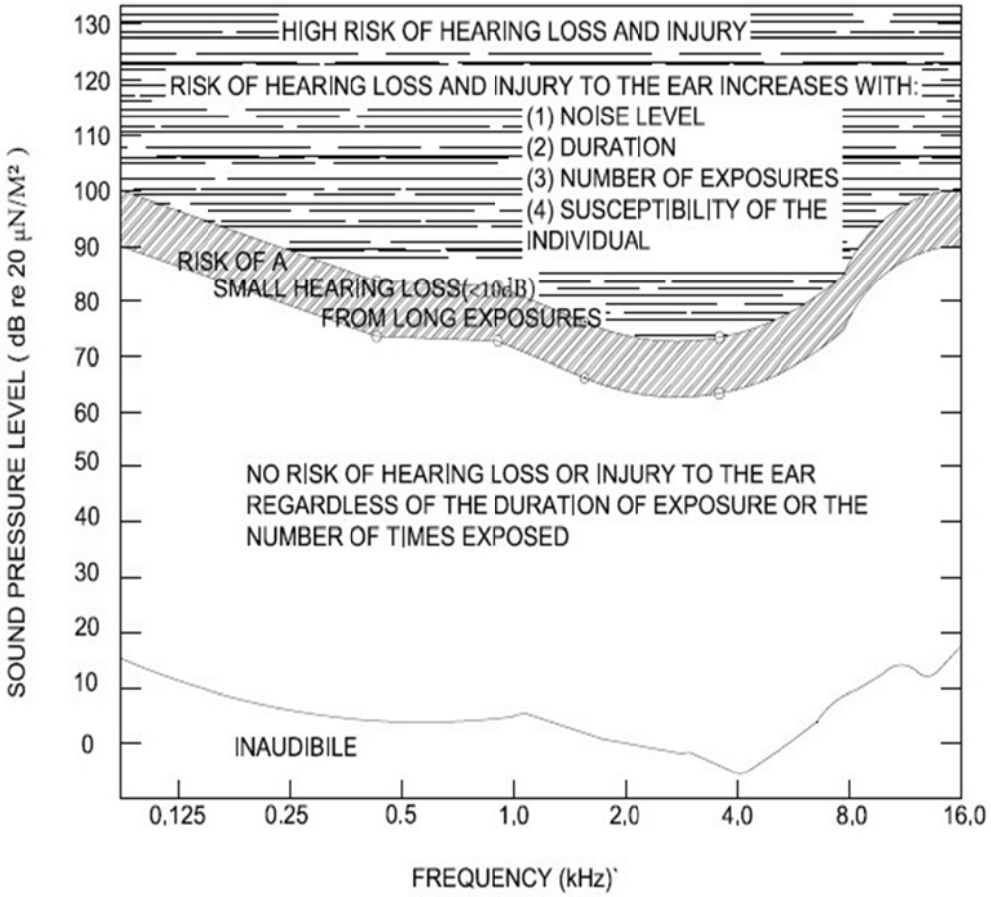

Figure 6. Range of human audibility categorized with respect to the likelihood of acoustic injury of the ear and NIHL (Mills & Going, 1982, p.250)

The studies of Mills and Going (1982, p. 250) signified that, even if a HPD is worn consistently with some attenuation levels below the action level of 85 dB(A), cochlear noise damage can still occur over the long run should the attenuated thresholds be above the psychophysical curves or critical levels for TTS. The risk of cochlear damage increases with an increase in noise level, duration of unprotected exposure, the number of exposures and individual susceptibility. It is further clear that damage criteria are not linear as found in existing regulations; cochlear damage can/will occur when noise exceeds the TTS base levels (biological threshold) for prolonged periods (De Muynck, 2007, p. 221). The MIRE protocol, as described by Ergotec/Hearing Coach, measures the ambient and residual noise levels (noise level measured behind the CHPD) where the results are presented in a graph against the critical levels (physiological criterion or BT). When the aim is *prevention* of cochlear damage, the residual

noise level (behind the HPD) should, according to Mills and Going (1982, p. 250), not be more than the physiological criterion for thresholds of the TTS base levels.

2.5 Summary

In this chapter, an overview was given of the effects of noise on the human ear, HCPs and legislation. Different types of HPDs were described as well as their attenuation effectiveness. A description of the two types of attenuation protocols, the MIRE and REAT were given.

The next chapter will focus on the methodology used to answer the research questions that are:

- What is the Noise Clipper® CHPD's attenuation effectiveness when used in normal working conditions?
- What is the workers perception concerning comfort levels afforded by the Noise Clipper® CHPD?

Chapter 3

Methodology

This chapter will comprise the research design, details of the population selected for the study, sampling/selection procedures, data collecting procedures, instrumentation and data analysis methods.

3.1 Introduction.

Research begins with a question in the mind of the researcher. A basic prerequisite for research is that the question be asked intelligently and in the presence of a phenomenon that the researcher observed and on which he/she needs more clarity or scientific evidence (Leedy, 1993, p. 7).

3.2 Research aims

With reference to the research problem, the following main research aim and sub-aims were formulated and are presented below.

3.2.1 Main aim

To evaluate the effectiveness of the Noise Clipper® CHPD used at an Implats mine**.**

3.2.2 Sub-aims

In order to answer the main aim the following sub-aims were formulated:

3.2.2.1 To evaluate the ambient noise levels;

3.2.2.2 To describe the ambient noise spectrum;

3.2.2.3 To evaluate the attenuation effectiveness of the Noise Clipper® CHPD as measured by the F-MIRE test protocol;

3.2.2.4 To evaluate the attenuation characteristics of the Noise Clipper® CHPD, measured against the BT for TTS;

3.2.2.5 To determine the subjects' perception of the comfort levels afforded by the Noise Clipper® CHPD;

3.2.2.6 To determine the self-reported wearing time of the Noise Clipper® CHPD.

3.3 Hypothesis

If the Noise Clipper® HPD is custom made, seal tested and fitted under the guidance of suitably qualified audiometricians, then attenuation should be constant and consistent over time and workers would perceive it as being comfortable to use for a full eight hour work shift.

3.4 Research design

The research design guides the researcher to solve the research problem. It provides the structure for the procedures to be followed, the data to be collected and the method of data analysis that were used (Leedy & Ormrod, 2005, p. 85).

It was decided to use an exploratory research design because it is suitable for the description of phenomena as they exist. An exploratory research design was used to identify and obtain information on a particular problem or issue where there are no earlier or few studies to refer to. The research approach was both quantitative and qualitative within the chosen design. Leedy and Ormrod (2005, p. 105) are of the opinion that by combining both quantitative and qualitative methodologies in research, a study will be greatly enhanced. The sub-aims of the research were divided into two research designs. A quantitative approach was utilised to measure the attenuation properties of the Noise Clipper® CHPD and to evaluate the noise spectrum that workers are exposed to. A quantitative research approach was used as it is designed to ensure objectivity, generalizability and reliability (Weinreich, 2006, p.1). Quantitative research involves the systematic collection of numerical information and implementing specific statistical procedures for the analysis of the data collected (Polit & Hungler, 1995, p. 15).

A qualitative research methodology was used to determine the subjective comfort levels afforded by the Noise Clipper® CHPD and the self-reported wearing time. This type of research is characterized by deductive reasoning, objectivity, the use of a structured instrument and statistical data analysis procedures (Glesne & Peshkin, 1992, p. 7). The research needs to explore possible correlations among specific observed phenomena as they are and will not change or modify the situation under investigation (Leedy & Ormrod, 2005, p. 179).

3.5 Sample population

In this section the criteria for subject selection are discussed as well as the procedures followed in setting these criteria. The results of the survey are not more reliable than the quality of the population or the representatives of the sample (Leedy & Ormrod, 2005, p. 207). In the selection process care was taken to ensure that the selected sample would be to representative of the population under study because a non-representative sample could have a detrimental effect on the external validity of the specific research (Leedy & Ormrod, 2005, p. 198).

3.5.1 Criteria for the selection of subjects

The criteria that were set for the selection of subjects are discussed below.

3.5.1.1 All subjects had to have a normal external ear structure

Abnormalities in the concha and meatus can affect the comfort and leak-tightness of the CHPD (Vinck, 2007, p.18). Potential subjects who were identified with foreign bodies, otitis externa, excessive cerumen, soft tissue, or bony growths in any of these structures were excluded from this research, because these conditions could affect the measurements for assessment of the effectiveness of the Noise Clipper® CHPD.

3.5.1.2 All subjects had to be employed at the selected platinum mine

The study was conducted with subjects using the Noise Clipper® CHPD in the selected mine. The Rustenburg division of the Impala Platinum mine group was selected because of the number of Noise Clipper® CHPDs in use.

3.5.1.3 All subjects had to be fitted with a Noise Clipper® CHPD

The aim of the study was to evaluate the effectiveness of the Noise Clipper® CHPD. Therefore, only subjects fitted with this device were selected to participate in the study. In the study of Arezes and Miguel (2002, p. 535) subjects were evaluated after a one-week's daily use of a HPD. At the Rustenburg division of the Impala Platinum mine group the, workers have been using the Noise Clipper® CHPD for more than one year (Pienaar, personal interview, 2007).

To date, more than 35000 Noise Clipper® CHPD units were fitted at the Rustenburg division of the Impala Platinum mine group. In the interest of validation of the results, all subjects who is said to have daily noise exposure levels of 85 dB(A) and higher were selected on a voluntary basis. Two groups of subjects were selected:

- The first group consisted of 250 underground workers irrespective of the area of work place. This group was targeted for the evaluation of comfort and usage through self-report.

- The second group consisted of 10 surface workers at Impala Platinum mine (Rustenburg division) and 10 contract workers (Marion, 2004, p.2) for the F-MIRE measurements. Only surface workers were selected for this part of the study because the instrumentation used is sensitive to underground working environments, that is, dust and humidity.

3.5.1.4 Informed consent

Only subjects who gave their full consent to participate in the study were selected. Research participants were fully informed of the nature, the purpose, and the risks of the study

and that each participant's involvement was voluntary (Appendix D). Workers were given the choice of either participating or not and were informed that they may withdraw at any time should they wish to do so (Schulte & Sweeney, 1993, p. 70).

3.5.1.5 Comments on selection criteria

Some researchers required literacy to be part of the selection criteria, but this research did not require of the subjects to able to read or write, since they were only required to sign for granting informed consent. As mentioned in the research design, a one-to-one approach was used where the researcher asked the questions verbally and the subject responded.

Some researchers found that male workers presented with a higher incidence of NIHL than females did. In a study by Ferrite and Santana (2005, p.48) it was found that the use of certain medications and nicotine could cause workers to be more susceptible to NIHL and that improper selection and utilization of HPDs were not the primary potential possible cause of PLH. AIDS-related diseases might affect every system of body, including the head and neck, causing eighth-nerve dysfunction which may include hearing loss (Sataloff & Sataloff, 2006, p. 354). The mining industry of South Africa is especially affected by the reality of workers with human immunodeficiency virus (HIV), (International Organization for Migration, 2010 p.9). It was decided not to exclude workers that were HIV positive, since the focus of the study was to evaluate the effectiveness of the Noise Clipper® CHPD in real world situations. Although these factors will not be used as selection criteria, it is important to bear them in mind in the interpretation of the research results.

3.5.2 Procedure for the selection of the sample population

Contact was made with the management of the targeted Impala Platinum mine Rustenburg division and a proposal was submitted concerning the intended research. This was done to reassure management that the informants' physical, social and psychological welfare will be protected and their dignity and privacy respected. The management's consent was subsequently granted (Appendix C). The safety and health manager of Impala Platinum assisted in the selection of subjects in the workshop that were to be used for the F-MIRE attenuation measurements. These subjects were to undergo otoscopic examinations which were conducted by the researcher.

3.5.2.1 Otoscopy

Prior to the F-MIRE attenuation measurement a visual examination of the external meatus and tympanic membrane and an otoscopic examination were conducted by the researcher on each subject. A hand held battery powered Welch Allyn 240 clinical otoscope was

used for performing otoscopy. Otoscopy was performed on seated subjects with the head tilted towards the opposite shoulder to account for the normal upward direction of the external meatus. For the otoscopic examination disposable, sterilized speculums were used. The helix of the ear was drawn backward and upward for the speculum (attached to the otoscope) to be gently inserted into the entrance of the external auditory meatus (Castillo & Roland, 2007, p.81). The inspection included visual examination of the pinna and concha as well as otoscopic examination of the external auditory meati. Although visual inspection of the tympanic membrane where made, no assurance could be given of the absence of tympanic membrane perforations without the use of tympanometry. The findings of the visual inspection of the pinna and concha and the otoscopic findings were recorded on a screening form as the one presented in Figure 7. A check mark was made in the corresponding space and a decision was made whether the subject passed or failed the evaluation. Should any of the observations be "Yes", the subject would not be selected for the F-MIRE measurements. Otoscopic examinations were performed on all subjects who consented to the F-MIRE measurements. The information gathered from the visual inspection and otoscopic will not be used for statistical analysis as it was only used as a tool for the researcher in the selection of test subjects.

Screening Form		
<u>Otoscopic findings:</u>		
Occluding wax:	Yes.	No.
Ear canal irritation:	Yes.	No.
Unusual canal characteristics:	Yes.	No.
Eardrum perforations:	Yes.	No.
Eardrum scar tissue:	Yes.	No.
Foreign matter:	Yes.	No.
<u>Visual inspection of pinna:</u>		
Deformities of pinna:	Yes.	No.
Scars of pinna:	Yes.	No.

Figure 7 Screening form: Otoscopic and unaided visual data

Owing to the size of the Impala Platinum mining group and the demographic spread of the mining population, all data were gathered at the Rustenburg division.

3.5.3 Description of the sample

Table 2. Age distribution of subjects used for comfort rating

Age		Gender	Subjects
<29	years	male	45
30-49	years	male	159
50- >60	years	male	36
Total			240

Table 3. Age distribution of subjects used for the F-MIRE measurements (permanent Impala Platinum mine employees)

Age		Gender	Subjects
<29	years	male	2
30-49	years	male	7
50->60	years	male	1
Total			10

Table 4. Age distribution of subjects used for the F-MIRE measurements (Maintenance contract workers employed at Impala Platinum mine)

Age		Gender	Subjects
<29	years	male	9
30-49	years	male	1
50->60	years	male	0
Total			10

It needs to be said that the subject demographics described above does not necessarily represent the South African platinum mining population as only one specific division of one platinum mine (Rustenburg division of Impala Platinum mine) were evaluated.

3.6 Material and apparatus used for the gathering of data

The material and apparatus used to collect the research data are discussed in this section. The first phase of the study was the real-world attenuation measurement using the F-MIRE method (Vinck, 2007, p. 20). The second part was the subjective evaluation of comfort afforded by the Noise Clipper® CHPD using a structured questionnaire referred to as a bi-polar comfort rating scale (Appendix A).

3.6.1 Hewlett Packard Miniature Handheld Acoustic Analyzer IE-33 (F-MIRE)

The Hewlett Packard Miniature Handheld Acoustic Analyzer IE-33 (Figure 8) was used for performing the F-MIRE measurements.

Figure 8. The Hewlett Packard Miniature Handheld Audio Spectrum Analyser IE-33 (Ivie Technologies Inc. 2004)

3.6.1.1 Description of the IE-33 technology for the F-MIRE measurements

The IE-33 can be described as a calibrated instrumentation-grade (TYPE I or TYPE II) audio analysis system built on a Pocket PC platform. Some of the functions include a real time analyser, FFT based with 1/1, 1/3, 1/6 octave bands from 25 Hz to 20000 Hz on ISO centres. It has a maximum resolution of 1024 data points and a maximum resolution display of 240 frequency data points (much greater than 1/2 octave). It incorporates a sound level meter with response modes fast, slow, impulse and peak and a selectable filter weighting of A, C or Flat. It has octave bandwidths at 250 Hz, 1000 Hz, 2000 Hz and 4000 Hz and meets ANSI S1.4-1983 Type 2 with supplied microphone Type 1, with optional Type 1 microphone preamp and capsule. The microphone has a frequency response of 20 Hz to 20000 Hz and uses an Electret Condenser element. The IE-33 has 9 temporary or "scratch" memories with a push button to save a memory. All temporary memories can be named and stored as standard tab delimited files. The maximum number of files is limited only by available memory on the Pocket PC. Memories are

stored at maximum resolution (1024 data points) regardless of real time analysis resolution setting (Ivie Technologies, Inc Lehi, U.T., 2004). Connected to the analyzer is a probe that contains two miniature microphones: one on the proximal surface, referred to as the measuring microphone, and the second one fitted in the distal part referred to as the reference microphone. The probe is inserted into a 2.5 mm canal in the body of the otoplastic (Figure 9) and fitted in a subject's ear (Fig 10). The probe was positioned in such a way that it does not interfere with the fitment of the CHPD. In Figure 11 the Hewlett Packard Miniature Hand Held acoustic analyzer and probe are connected to a personal computer.

Figure 9 The probe that contains two miniature microphones connected to an otoplastic for F-MIRE measurements (Vinck, 2007, p. 21)

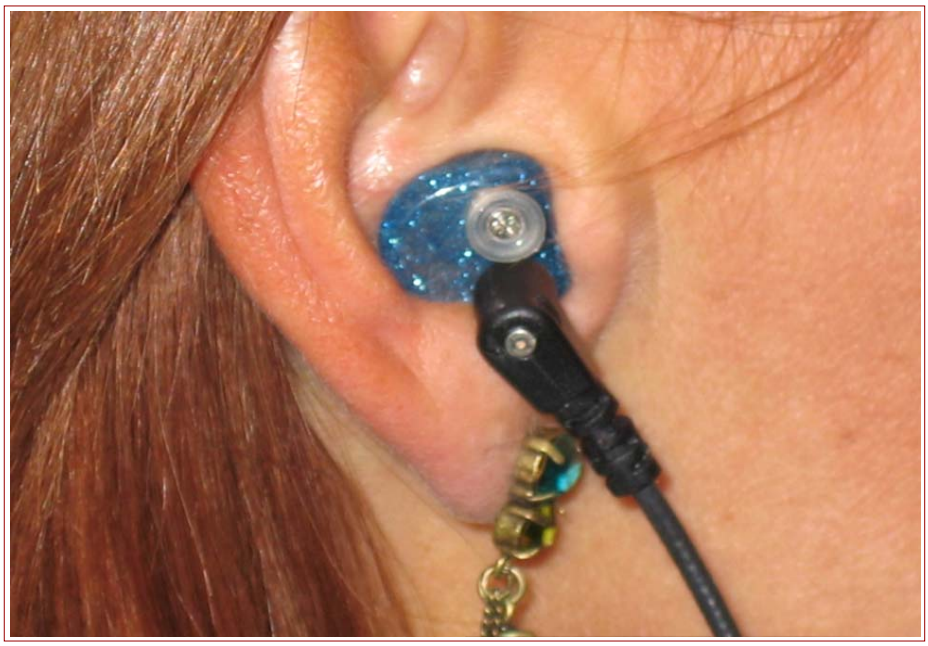

Figure10 The F-MIRE measurement probe connected to the otoplastic and fitted in a subjects ear (Vinck, 2007:21)

Figure 11 The Hewlett Packard Miniature Hand Held acoustic analyzer and probe connected to a Personal Computer (PC) (Vinck, 2007, p.21)

3.6.2 Otoscope

A hand held battery powered Welch Allyn 240 clinical otoscope was used for performing otoscopy.

3.6.3 Noise Clipper® CHPD

All permanent employees of the selected Impala Platinum mine were fitted with the Noise Clipper® CHPD described in chapter 2 under heading 2.3.5 Hearing protection equipment.

3.6.4 Hand drill

A Dremel MultiPro hand drill was used for drilling the second canal used for the insertion of the probe microphone in the otoplastic body (the first canal is used in connection to the filtering device).

3.6.5 Attenuation control unit

Figure 12. The attenuation control unit and its connection to an otoplastic (Vinck, 2007, p. 18)

The measurement and verification of leak-tightness must form part of an attenuation measurement protocol (Vinck, 2007, p. 21). The attenuation control unit is supplied by Ergotec Netherland and developed by ES International. This unit was specifically developed for the evaluation of leak-tightness of CHPD devices. The attenuation control unit and a schematic

illustration of how the attenuation control unit is connected to the otoplastic can be seen in Figure 12.

3.6.6 Description of the bi-polar comfort rating scale

As a result of the literature search the researcher identified some factors that seemed to correlate with indices describing comfort features for HPDs. The following descriptors in determining the subjective comfort perceptions of the workers using the Noise Clipper® were selected.

During a full eight hour work shift the Noise Clipper® should not:

- cause any painful sensations in the ear canal ;
- work loose and eventually fall out of the ear;
- be annoying or bothersome to use;
- cause uncomfortable pressure in the ear canal;
- be perceived as heavy and/or rough;
- lead to a feeling of complete isolation;
- be uncomfortable to wear.

In the studies of Arezes and Miguel (2002, p. 534) and Park and Casali (1991, p, 159) on comfort evaluation of HPDs, rating scales were used with essentially the same descriptors as mentioned above. It was decided to use the bi-polar comfort rating scale as suggested by these authors (Arezes & Miguel, 2002, p. 534; Park & Casali, 1991, p. 159). For the bi-polar rating scale two word pairs consisting of adjectives describing comfort such as “painless-painful” and “comfortable-uncomfortable” were used. An example of the bi-polar comfort rating scale is provided in Appendix A. The rating scale descriptor pairs had no particular directional orientation with respect to the second scale item that is considered the most centre scale to the subject’s perception of comfort (uncomfortable-comfortable). The same method of scoring of the individual sub-scales, using reverse coding, described by Arezes and Miguel (2002, p. 533) were used in this study. A scale item with a different orientation to the central scale (second in the grid) was reversed to maintain a consistent directional relationship to the comfortable-uncomfortable scale. Reversed coding was used so that the scale’s items had different orientations than the centre scale (uncomfortable-comfortable) and it was randomly varied. In the original questionnaire, the scale items (sub-scales) were placed in such a manner that the direction of the descriptors did not mimic that of the uncomfortable-comfortable scale. For instance, if wearing the Noise Clipper® was perceived as painless the descriptor would be one,

while if it was perceived to be complicated to fit, the descriptor on the rating scale would be seven. This was done to eliminate guessing and to neutralize the "halo" effect that influences independent judgment of each scale and negatively affects the validity of data. A value of one describes the scale item to be most comfortable and a value of seven to be most uncomfortable. An example is that, if the subject marked the first sub- scale item in the left space and considered wearing the HPD as painless, the initial score was one, but as this sub-scale had a different orientation, the value was reversed to become seven, because this was the most comfortable option in this sub-scale for "pain".

At the end of the questionnaire, the subjects had to indicate usage time in hours per shift. A four-point scale was used to eliminate the middle order effect. Time intervals of use were indicated as eight hours, six hours, four hours, and two hours. As explained by Arezes and Miguel (2002, p. 535) this self-reported HPD use can be seen as a reliable measure since it was validated by Lusk, Hong, Ronis, Eakin, Kerr and Early (1999, p. 491). The official language spoken at the mine is English, but the dominant language spoken by the workers is Setswana (Schophaus personal interview, 2007). The questionnaire was drafted in English and then translated into Setswana (Appendix B) by Dr I Kock (an African-language specialist).

3.7 Ethical clearance

The research proposal was approved by the Research Ethics Committee of the Faculty of Humanities of the University of Pretoria and the pilot study could be designed (Appendix E).

3.8 Pilot study

A pilot study was conducted to determine how the process of data collection would transpire. Well-designed and well-conducted pilot studies will improve the internal validity and reliability of the research instruments (Van Teijlingen & Hundley, 2002, p. 2).

Measuring instruments developed in the United States or Europe may not be easily applicable to the multi-ethnic and multicultural society of South Africa (Mouton, 2005, p. 102). The questionnaire used in this study was previously validated by Arezes and Miguel (2002, p. 535), Park and Casali (1991, p. 154) and Christian (2000, p. 65). The comprehension by the subjects of the content of the questionnaire needed to be evaluated as well as the commonly understood way of communication . Furthermore, the time frame needed for the administration of the questionnaire and the F-MIRE attenuation measurements needed to be determined.

The pilot study allowed the researcher to construct specific procedures for the collection of data in order to allow for any necessary changes in the evaluation/ measurement procedures to be followed (Woken, 2008, p.1). This study used a combined research approach: a

quantitative approach that was utilized to measure the attenuation properties of the Noise Clipper® CHPD and for the evaluation of the noise spectrum of exposed workers; and a qualitative research approach to determine the subjective comfort levels afforded by the Noise Clipper® CHPD. Therefore, two pilot studies were conducted. The first comprised the measurement of the noise spectrum to which workers were exposed and the evaluation of the attenuation properties of the protection device, using the F-MIRE technique. The second pilot study included the evaluation of the subjective comfort levels afforded by the Noise Clipper® CHPD and determining the self-reported wearing time of the HPD by making use of a questionnaire.

The line managers were reluctant to release 20 workers for the F-MIRE measurement because they were concerned that production would be negatively affected. After discussions with management, authorization was given to release not more than 10 workers for the F-MIRE test. For the validation of the results, Marion (2004, p. 2) suggests at least 20 workers are to be used for the F-MIRE. Although this study aims to evaluate the Noise Clipper® CHPD in the Impala Platinum mine group, twelve contract workers of a company doing maintenance at Impala Platinum mine in Rustenburg that also used the Noise Clipper® CHPD where selected. The management of the maintenance company was consulted and 12 workers were released for the F-MIRE measurements. From the maintenance company, two workers were selected for the pilot study and 10 for the main study. The same selection criteria applied to these workers and the consent form was signed by all subjects partaking in the study (Appendix D). In order not to offend the management of the Impala Platinum mine, it was decided to conduct the pilot study on workers of the maintenance company. F-MIRE measurements were made in the same workshop intended for the measurements of the Impala Platinum mine workers. The data collected on these two subjects was not used in the final evaluation.

The safety and health officer of the Rustenburg division of Impala Platinum assisted in the selection of the test subjects. An office close to the workshop was used for the otoscopic evaluation and the preparation of the Noise Clipper® CHPDs. After selecting the subjects, visual inspection of the auricle and otoscopic examinations were conducted by the researcher. The results were recorded on the evaluation form (Appendix E). One of the subjects presented with an obstructive cerumen plug and was referred to the medical station for its removal and was not used for the F-MIRE measurements. He was replaced by another contract worker who complied with the selection criteria and consented to participate. The researcher collected the Noise Clipper® CHPDs from the subjects who complied with the selection criteria for the preparation of the leak-tight evaluation and the F-MIRE. Using a Dremel MultiPro hand held

drill a 2.5mm drill bit was used to drill a second canal into the body of the Noise Clipper® CHPD. The devices were subsequently returned to the subjects and they were asked to insert them as they normally do. A leak-tight verification was done on the device starting in the right ear using the attenuation control unit. With the leak-tight evaluation, it was found that one of the subjects had a leak in one of his Noise Clippers® CHPDs. Only subjects with leak-tight devices were selected for the F-MIRE measurements, therefore the worker was replaced by another worker who met the selection criteria and signed the consent form. After the leak-tight evaluation, the F- MIRE microphone probe was inserted into the body of the Noise Clipper® CHPD. Special care was taken to ensure that the probe fitted securely in the body of the otoplastic in order to measure the actual noise spectra (ambient noise) and the attenuated sound pressure level (noise reduction) behind the HPD in the meatus of the subject.

The first subject was instructed to fit the Noise Clipper® CHPD as he normally would and the F-MIRE measurements were made. Measurements were made as suggested by Ivie Technologies Inc. and described in the owners' and operators' manual (Ivie Technologies Inc, 2004, p. 13-22).

All measurements started with the right ear. For the measurement of ambient noise levels, the real time measurement switch "**R"** was selected and the measurement was made. The scratch memory location 1 on the iPAQ/IE-33 was selected and the measurement data stored in the Scratch file. The "**M"** position on the switch was then selected for the real time measurement behind the HPD (noise reduction) in the meatus.

The same procedure was followed for storing the data in the scratch 2 file. The memory screen was opened and the store function selected next to the Scratch 1 .ivi for the reference data (ambient noise levels) and the Scratch 2 .ivi, for the attenuated data to be saved in the memory program of the IE-33. In the "Save as" screen care was taken to ensure that the files were named correctly. After the measurements were made, HPD was removed and the same process followed for measurement in the left ear. Two measurements were performed on both the subjects to determine test reliability and to obtain a measure of reproducibility. As with the study of Neitzel et al., (2006, p. 4), the results were visually examined for irregularities and unusual attenuation patterns. As was expected, the ambient noise levels for the frequency range 125 Hz to 6000 Hz fluctuated (free field, real-world noise levels). The results of the attenuation levels indicated that one of the subjects showed higher levels at 125 Hz than the ambient noise levels. This meant that the Noise Clipper® CHPD amplified the noise at this frequency. The device for this subject was removed for visual inspection. No obvious faults could be found with either the filter mechanism or the body of the HPD. The fit of the microphone probe was

checked and the leak-tight test was repeated. The Noise Clippers® CHPD was found to be leak-tight. The device was handed back to the worker and he was instructed to fit the device as he usually would, without assistance by the researcher. The F-MIRE measurement was repeated and rendered the same results. Neitzel, et al. (2006, p. 5) excluded subjects that presented with this type of results (amplification of sound by the protector) because they concluded that such findings would not be accepted in real-world situations. It was decided to include such findings in the present study, as the aim was to evaluate the Noise Clipper® CHPD in real-world situations. The attenuation levels for all the other centre frequencies were consistent within a 1 dB to 2 dB range. The results of the two tests indicated that the measurements were consistent. The reproducibility was verified by comparing the results from the repeated measurements. The F-MIRE measurement information was stored in the IE-33 acoustic analyzer for each subject tested. The total time used for the F-MIRE measurement was 32 minutes; a breakdown is given in Table 5.

For the second pilot study five subjects, who complied with the selection criteria and signed the consent form (Appendix D), were selected for completion of the questionnaire. Due to the low education levels of the subjects and the high validity demanded by this study, each subject was individually consulted, observed, and interviewed by the researcher (assisted by the African language expert). It was envisaged that the most appropriate methodological tool for this part of the study would be a bipolar rating scale (Appendix A) (Arezes & Miguel, 2002, p. 534, Christian, 2000, p. 65 and Park & Casali, 1991, p. 154).

Prior to the interviews, the mine safety officer assisted with the consent forms in that he presented it to the subjects and explained the content if not fully understood. The subjects that gave their consent were sent to the interview room and asked to be seated next to the researcher (accompanied by the African language expert). The subject were handed the bi-polar rating scale and was instructed to respond to the comfort descriptors by marking the appropriate scales. It was explained to the subject that should he have any difficulty in understanding a descriptor he was to ask the researcher for clarifications. It was found that some of the sub-scales had to be explained. A number of the subjects had difficulty in understanding “tolerant/intolerant” and “feeling of complete isolation/no feeling of complete isolation”. The African language expert had to explain these concepts to the subjects. The explanation was: “tolerant/intolerant” was the Noise Clipper® acceptable to use or not, and “feeling of complete isolation/no feeling of complete isolation” did it feel that you are cut-off from your environment while using the Noise Clipper® or not. It was decided not to change these comfort descriptors on the rating scale and that the concepts would be explained/ describe (as above) should the subjects experience

difficulty in understanding. The researcher was then of the opinion that the subjects showed good comprehension of the questionnaire and understood the contents of the consent form. The interpreter did not have to further explain in Setswana. The results of the questionnaire were recorded on the bi-polar comfort rating scale (Appendix A.) The data collected during the pilot study was not used in the main study. The total time needed for the one-to-one interviews was 10 minutes (Table 5).

In order not to affect production or other mining operations, it was envisaged that the subjects were to participate in the study after a work shift. It was established that the workers used a transport system that took them to the hostels after their daily shifts. The concerns were that if they had to walk back to the hostels, they would be reluctant to partake in the study. The Noise Clipper® Company personnel (Pretorius, personal interview, 2009) suggested conducting the research at the medical station during normal work hours. All Implats workers have to comply with a certificate of fitness at the mine's Occupational Health Centre after returning from leave (Schophaus, personal interview, 2009). The researcher discussed this with the Impala Platinum management of the Rustenburg division, and authorization was given to conduct the study at the Occupational Health Centre during normal working hours. The subjects used for this part of the study had to comply with the selection criteria and had to sign the form granting informed consent (Appendix D).

The pilot study resulted in the procedure/time breakdown as presented in Table 5.

Table 5 *Time breakdown for pilot study (1) and (2)*

Pilot study (1):
• Otoscopic examination: 2 minutes per subject
• Drilling of second canal: 5 minutes per subject
• Attenuation control unit leak-tight testing: 5 minutes per subject
• F-MIRE measurement: 10 minutes per ear
• **Pilot study (2):**
• The comfort rating questionnaire: 10 minutes per subject
Total testing time: • Pilot study (1): 32 minutes
Total testing time: • Pilot study (2) : 10 minutes

With the knowledge gained and adaptations made from the pilot study the formal data collection

process for this study could begin.

3.9 Procedure for the collection of data

The following procedures were carried out for the collection of data:

3.9.1 The F-MIRE measurement

The steps taken in the attenuation measurement using the protocol for F-MIRE are discussed in the Sections 3.7.3.1 to 3.7.3.6.

3.9.1.1 Leak-tight verification

Only surface workers (n=20) who accepted and signed the form granting informed consent form (Appendix D) were selected for this phase of the study. Leak-tight verification was done on the Noise Clipper® CHPD device using the attenuation control unit. For the leak-tight verification, a second canal had to be drilled into the body of the Noise Clipper® CHPD. The researcher ventilated the otoplastics on site and made use of a Dremel MultiPro hand drill with a 2.5 mm drill bit. The attenuation control unit was connected to the otoplastic that was placed in the subject's ear canal. The attenuation control unit generated an overpressure of 10 mbar in the cavity between the otoplastic and the tympanic membrane. When a stable system was measured over three seconds (with overpressure of 10 mbar in the cavity), the test was described as positive and verified the otoplastics leak-tightness. If the system became unstable over three seconds the leak-tight test result was negative and the subject was not used for the F-MIRE measurement. The results were displayed on a digital screen and were recorded for possible later analysis. The second canal was later used for the placement of the probe containing the two microphones. After the measurements were completed the second canal was sealed by plug supplied by the Noise Clipper® Company. It needs to be mentioned that the vent diameter and the probe tip needed to correlate to ensure that the vent was completely sealed (Neitzel et al., 2006, p. 13).

3.9.1.2 The real time analysis measurement

Experience gained from the pilot test was implemented for the formal F-MIRE measurements. Prior to testing, the researcher inserted a probe consisting of two microphones developed by Ergotec, Netherlands into the Noise Clipper® CHPD, utilizing the same canal used for the leak-tight evaluation. The reference microphone measures the noise reduction (real time analysis level) behind the HPD in the meatus of the subject (Vinck, 2007, p. 20). Three separate measurements on each subject were conducted over three days. These multiple measurements on each subject provided a measure of between-subject and within-subject variability and yielded a better statistical basis for device performance (Lancaster & Casali,

2004, p. 12). The real time analysis of the ambient noise and the real time analysis behind the HPD were captured per centre frequency. The measurements were made on test subjects in real-world settings with HPDs fitted by the subjects themselves. No assistance was provided with fitting and no readjustments were made by the researcher (Neitzel et al., 2006, p. 6).

3.9.1.3 System setup for the real time analysis measurements (F-MIRE)

The iPAQ/EE-33 acoustic analyzer was placed into a cradle (supplied), one day prior to testing. This was done to ensure that the unit was fully charged for the measurements to be carried out in the workshop. For the real time analysis a sample rate of 4400 Hz were used that collected 1024 data points over a 20 Hz to 20000 Hz bandwidth with each sample. When a data sample was stored, all 1024 data points were accessible for analysis. This allows a recalled memory to be displayed in any resolution desired for data analysis (Ivie Technologies, Inc, 2004, p. 2). The data for ambient noise levels and noise reduction were recorded and captured in the spectrum analyzer. Correction factors to address the transfer function for the F-MIRE measurements where pre programmed in the iPAQ/EE-33 acoustic analyzer. A Microsoft Excel template that facilitated the plotting, analyzing and printing of test data acquired with the IE-33 was used for data capturing.

The following steps were taken to program the iPAQ/IE-33 for the F-MIRE measurements:

- The unit was turned on and the start menu selected.
- The IE-33 icon was activated on the screen, using a stylus and the loaded memory files.
- The function options were displayed on the screen and the following selections were made using the real time analysis controls:
  - 1/1 Octave measurement resolution was selected
  - setting for fast measure response

Ergotec Netherlands developed and calibrated a dual microphone system used for the measurements in this study. The dual microphone cord, attached to the analyzer, has a microphone selection switch for the real time measurement of ambient noise and attenuation measurement. It is marked "**R**" for reference microphone and "**M**" for attenuation microphone activation. All measurements were made starting with the right ear and measuring real time measurement of the ambient noise (**R** switch selection). The scratch memory location 1 on the iPAQ/IE-33 was selected and the measurement data stored in the scratch 1 file. The **M** position on the switch was then selected for the real time measurement behind the Noise Clipper® CHPD (noise reduction) in the meatus. The same procedure was followed for storing the data in

the scratch 2 file. The memory screen was opened, the store function selected next to the Scratch 1 .ivi for the reference data, and the Scratch 2 .ivi for the attenuated data, to be saved in the memory program of the IE-33. In the “Save as” screen, care was taken to ensure that the files were correctly named. This stored data was later downloaded and synchronized with the HearingCoach® MIRE software on a personal computer. Measurements were performed unilaterally (one ear at a time). Figure 13 presents a representation of the hard copy of the F-MIRE measurement reports (developed by HearingCoach® in cooperation with the University of Ghent). The top part of the form reflects the ambient noise levels measurement per 1/1 centre frequency while the bottom part is the attenuation data measured behind the otoplastic.

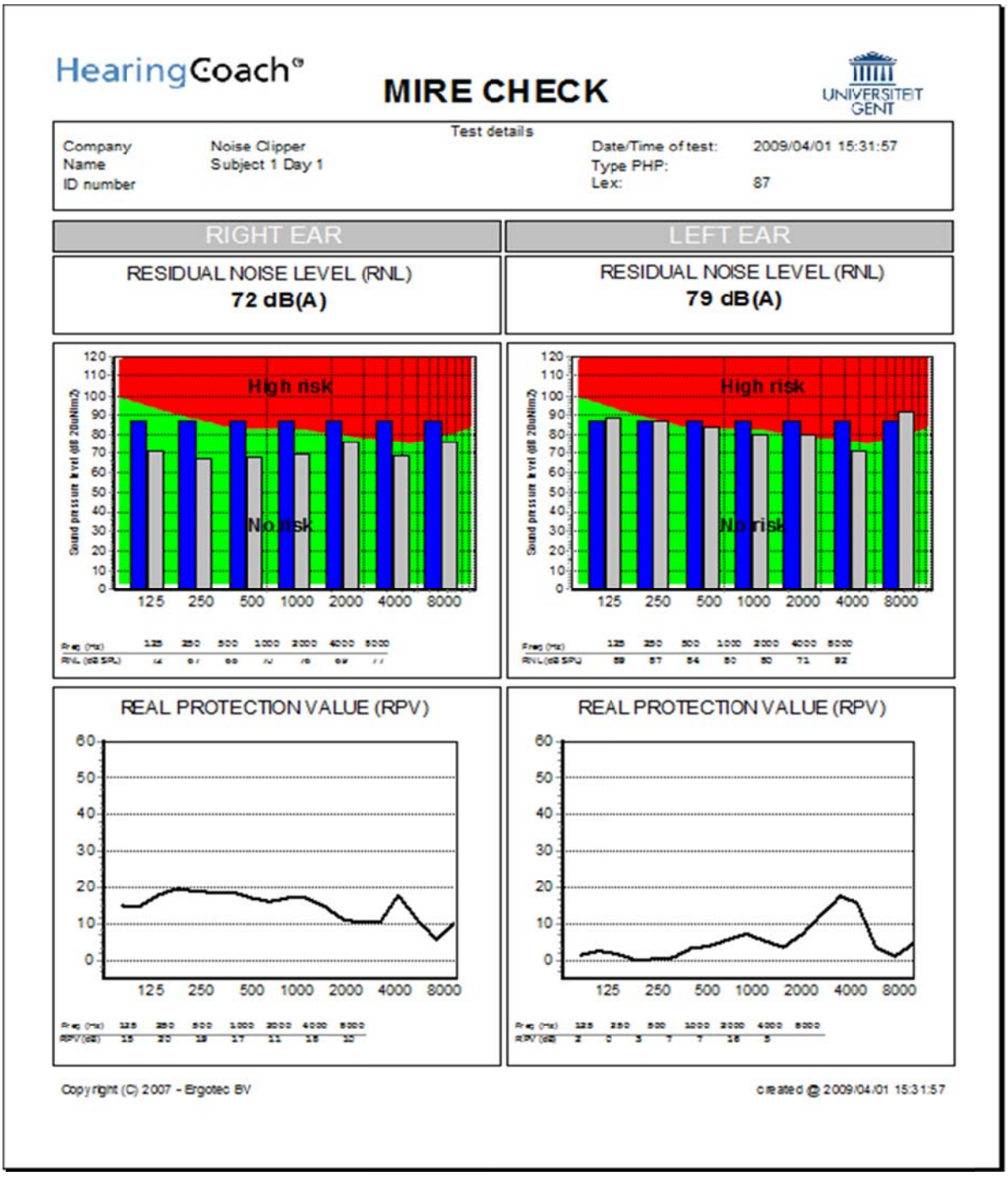

Figure 13. The F-MIRE report on residual noise levels and real protection values (Hearing Coach®, 2008)

3.9.1.4 Correct implementation of the Noise Clipper® CHPD

For the purposes of this study it is important that the HPD device should be fitted correctly. During initial fitment of the Noise Clipper® CHPD, personnel from the distributing company instructed individual users and demonstrated the fitment procedure. The workers had to indicate that they understood the instructions and were also required to demonstrate their ability to fit the protectors correctly (Noise Clipper® Manual, 2007, p. 14). Compliance with

the directions was not monitored as the purpose of this study was to measure real world attenuation in real world settings. During evaluation the subjects therefore had to fit their HPDs as they normally would, without any instruction or guidance.

3.9.1.5 The F-MIRE test procedure

The F-MIRE attenuation measurement was conducted in the subjects' normal working environment where noise levels were said to be above 85 dB(A) (information supplied by the Noise Clipper® Company). The type of equipment found in this specific workshop consisted mainly of conveyer belts and stone crushing units. General maintenance on these machines is carried out in the workshop where F-MIRE measurements were made. Besides the noise generated by the conveyer belts and stone crushers, angle grinders, hammers and welding machines was used for maintenance work. Approximately thirty five employees work in this workshop while 3 employees were assigned for machine maintenance. In a study conducted by Chandna, Deswal, Chandra and Sharma (2009, p. 85) they described industrial noise problems to be complicated by the fact that noise generated are confined to the room or workshop. "Reflections from the walls, floor, ceiling and equipment in a room create reverberant sound field that alters the sound wave characteristics from those from the free field" (Chandna et al., 2009, p. 85). Safety areas were demarcated in the workshop and the researcher was limited to certain designated safety areas for the F-MIRE measurements (the same areas used by the machine operators on which the measurement were made).

The subjects were informed of the procedure that was to be followed and that the measurement would last not more than 10 minutes (as determined by the pilot study). The subjects were further instructed to remain silent and not talk during the measurement.

Before the probe was inserted into the otoplastic, a leak-tight test was performed, using the attenuation control unit. If leak-tightness was not confirmed the subject was eliminated from the measurements. The Noise Clipper® CHPD was removed from the subject's ear and the probe was inserted into the otoplastic, handed to the test subject, and instructed to fit the device as he normally does. Real time analysis for the noise spectrum was measured and recorded (the monitoring microphone) and the reference microphone measured the real time analysis (attenuated) thresholds behind the HPD. The noise reduction thresholds are the attenuation effected by the Noise Clipper® CHPD as measured with a dual microphone system. This measure was computed by subtracting the ambient measured levels from the attenuated noise levels behind the Noise clipper® CHPD. The results of these calculations are referred to as noise reduction measurements and are given in dB(A) (Neitzel, et al., 2006, p. 3). A 110 dB

filter settings (attenuation) was selected in the Noise Clipper® CHPD (Pretorius, personal interview, 2009). Hard copies of the results were made for each test subject, stored for statistical analysis and will be archived for 15 years.

3.9.1.6 Completion of the bi-polar comfort rating scale

Mouton (2005, p. 79) described reliability as the focal point of the data collection phase, implying that the use of a reliable measuring instrument on different groups in different circumstances must lead to the same observation.

Informed consent was obtained from the management of the Rustenburg division of the Impala Platinum mining group (Appendix C). In view of the size of the mining population, its demographic spread and limited time and other resources a short, personally administered questionnaire (Appendix A) was used in a one-to-one setting. Office space in the medical station was made available to allow the researcher (and the African language expert) to be in a one-to-one setting with the worker. A one-to-one setting is an important requirement as the respondent might otherwise be influenced by other respondents, affecting the validity of the questionnaire. The questions were in English (Appendix A), but because of the possibility that some respondents might have different levels of understanding, a questionnaire in Setswana was also prepared and made available (Appendix B). Subject responses were recorded by the researcher on the bi-polar rating scale.

The researcher briefed a language expert that was a member of the research team and assisted with the survey in terms of the questions to be asked, as well as their interpretation. Kahan and Ross (1994, p. 41) cautioned that assistants needed to be instructed to adopt a neutral and objective stance while keeping as close as possible to the original phrasing of the questions in order to avoid any form of bias. This was explained to the language expert who assisted with the translations.

The authors of the *Survey System's Tutorial* made the following remark concerning research done in third world countries: "Respondents have a strong tendency to exaggerate answers**"**, and they may perceive researchers as being government agents with the power to punish or reward according to the substance of their answers (*The Survey System's Tutorial*, 2001, p. 16). For this reason the researcher emphasized the fact that the research were conducted for academic purposes and that no personal information of the subjects will be revealed to management of the Impala Platinum mining group. Responses were manually recorded on the questionnaire for later statistical analysis.

3.10 Procedure for the capturing of data

All the raw data per sub-aim (numerical) were organized into a form that allowed

manipulation so that statistical techniques could be applied. The data of the F-MIRE measurements were transferred from the iPAQ/IE-33 software to an ASCII data file and transported to a Microsoft Excel spread sheet. Using the information recorded on the spread sheet, the data were imported into the software *Statistical Package for the Social Sciences 19* and statistical analysis was performed using this package. The same statistical package was used for the data processing of the bi-polar comfort rating results. By making use of this software program descriptive and analytical statistics were obtained utilizing tables and graphs.

3.11 Procedure for the processing and analysis of data

This study aimed to explore and identify possible correlations and characteristics among observed phenomena that were measured in real-life situations (Leedy & Ormrod, 2005, p. 179). Analysis of data the will allow the researcher to "understand the various constitutive elements" to determine patterns, trends or relationships between concepts, constructs or variables in order to identify, isolate or establish themes in the data obtained (Mouton, 2005, p. 108).

Theoretical frameworks and models for the results of this study are confirmed in the research of Arezes and Miguel (2005, p.535); Lancaster and Casali (2004, p. 14); Neitzel et al. (2006, p. 6) and Park and Casali (1991, p. 158). The findings and conclusions pertaining to the main and sub-aims will be summarized and the conclusions supported by the data collected and interpreted (Leedy & Ormrod, 2005, p. 287).

Leedy and Ormrod, (2005, p. 235), described statistical analysis as a tool for making numerical data more meaningful because it explores the nature and inter-relationships of data. In order for statistical techniques to be employed, the data must first be organized into a form that will allow its manipulation. The procedures for the analysis of test data will be discussed according to the aims of the study.

3.11.1 The evaluation of the ambient noise levels

The overall ambient noise level in the workshop was measured and computed by means of descriptive statistics. The average noise levels for the different centre frequencies are expressed as an arithmetic mean, and different measures of variability (range, standard deviation, and interquartile range, which is equal to the difference between the upper [percentile 75] and the lower quartiles [percentile 25]). Standard deviations and percentiles were calculated to determine if fluctuations of noise levels exist. The data of the average frequency spectrum of ambient noise levels per centre frequency as well as 95% confidence intervals were presented in a table and visually demonstrated in a graph. To determine if the differences between the low and the high frequencies are statistically significant an analysis of variance (ANOVA) were

carried out (Roberts & LLardi, 2003, p. 105). To determine what the effect would be of the measurements over three consecutive days a two ANOVA (Roberts & LLardi, 2003, p. 105) were done, using day of measurement and frequency as independent variables to determine whether there is a significant difference between the mean noise levels at different centre frequencies over the three days. The results of this analysis are presented in Table 6 . A post hoc analysis of the data collected over the three days were done to determine if the noise levels between the three days were statistically significant.

3.11.2 To evaluate the attenuation effectiveness of the Noise Clipper® CHPD as measured by the F-MIRE test protocol

The number of measurements, (N), mean attenuation levels, their standard deviations, and ranges (from maximum to minimum) per centre frequency, measured over the three consecutive days were calculated and presented in a Table. A one-way ANOVA (Roberts & LLardi, 2003:102) were performed to evaluate if the mean attenuation values observed between the different centre frequencies were significantly different from each other. Frequency was used as the independent variable and attenuation (in dB) as the dependent variable for this analysis. A post-hoc Scheffé method (Roberts & LLardi, 2003, p. 109) was applied to determine if there is a significant difference of the attenuation level at all the frequencies measured over the three days and if it differed significantly from each other. The consistency and nature of the attenuation over time was also evaluated and if this trend can be reproduced over three consecutive measuring days. A correlational analysis was carried out on the observed F-MIRE data. A two-tailed Pearson product-moment correlation coefficient (*r*) (Welkowitz, Ewen & Cohen, 1998, p. 175) was calculated.

To determine if the measurement results of the two attenuation protocols (F-MIRE versus REAT) were related a Pearson-*r* correlation coefficient (Welkowitz, et al., 1998, p. 175) was calculated. A two tailed Pearson correlation analysis (Welkowitz, et al., 1998, p. 175) was done between the assumed protection value (assumed protection value REAT- results) of the Noise Clipper® and the F-MIRE attenuation results to determine if a significant correlation existed between these two measuring protocols and to determine the extent to which the values of the two variables are related.

3.11.3 The evaluation the attenuation characteristics of the Noise Clipper® CHPD, measured against the BT for TTS;

A comparison was made to determine if the Noise Clipper® attenuated noise below the BT for TTS. Distribution of the differences between the BT for TTS and the residual noise levels across frequencies based on the F-MIRE protocol, were expressed in percentiles. This was done to

determine if the differences were statistically significant.

3.11.4 The determination of the subjects' perception of the comfort levels afforded by the Noise Clipper® CHPD

Correlations were made between the different sub-scales and the comfortable-uncomfortable scale. In the present study all sub-scales were treated as significant and were included in the results of the descriptive statistics and presented in Table 17.

3.11.5 The determination of the self-reported wearing time of the Noise Clipper® CHPD.

For determining the self reported wearing time the Frequency procedure was used. Using this procedure the usage time could be broken down in percentages according to the four time limits given at the end of the questionnaire.

Chapter 4

Results

In this chapter the results will be presented according to the aims set out in the Chapter 3 of this report.

4.1 Evaluation of the effectiveness of the Noise Clipper® CHPD

In order to describe the effectiveness of the Noise Clipper®, the characteristics of the existing ambient noise levels in the workshop need to be described. These characteristics include overall ambient noise level, influence of centre frequency (spectral composition) and time of measurement on the observed noise level. The actual attenuation effectiveness of the Noise Clipper® will later be described in detail by comparing these ambient noise characteristics to the attenuation characteristics, as measured by the F-MIRE test protocol.

4.1.1 Characteristics of ambient noise.

The characteristics of the ambient noise are described in terms of the ambient noise level, the noise spectrum and the influence of time of measurement on the ambient noise level.

4.1.1.1 Description of the ambient noise level in the workshop

“The advantage of quantifying a source’s sound power level in real-world situations is that it provides an absolute quantification of the sound energy emitted by that source, irrespective of the acoustic environment (e.g. reflective or absorbent surfaces, the presence of other sources, etc.)” (Department of Minerals and Energy, RSA, 2003, p. 48). For this reason, noise levels were measured at random spots in a workshop of the Impala Platinum mine on 20 subjects using the IE-33 analyzer. The measurements where repeated over three consecutive days at the same time of the day. The results of the measurements are presented in Table 6.

Table 6 Mean ambient noise levels (dB A) per centre frequency measured in the workshop over three consecutive days

	Ambient Noise Level (dB SPL)					
Frequency	**Mean**	**Standard deviation**	**Minimum**	**Maximum**	**Percentile 25**	**Percentile 75**
125 Hz	74	12	45	95	66	82
250 Hz	75	10	52	90	66	83
500 Hz	78	7	58	90	78	83
1 kHz	81	5	65	90	80	83
2 kHz	83	3	69	89	81	84
4 kHz	84	4	67	90	83	86
8 kHz	85	3	74	90	85	87

Table 6 reflects both the average noise levels for the different centre frequencies, expressed as an arithmetic mean, and different measures of variability (range, standard deviation, and interquartile range, which is equal to the difference between the upper [percentile 75] and the lower quartiles [percentile 25]). The measured overall ambient noise level in the workshop was measured and computed by means of descriptive statistics.

The overall ambient noise level, across frequencies, was calculated as 80.55 dB(A) with a standard deviation of 3.54 dB. Although this level is below the South African legal limit of 85 dB(A) (SANS 10083, 2004), the measures of variability in the table indicate that the maximum observed levels ranged from 88 dB(A) to 95 dB(A) for all centre frequencies ranging from 125 Hz to 8000 Hz. From these data it is clear that, although the average ambient noise levels are below the legal limit of 85 dB(A), there is significant fluctuation of the noise levels found, sometimes exceeding this limit.

Both standard deviations and percentiles clearly demonstrate these fluctuations. For example, for the 4000 Hz centre frequency the observed upper and lower quartiles are 86 dB(A) and 83 dB(A) respectively. This means that the mid-spread or middle fifty (middle 50 %) of the total sound sample for that frequency lies between 83 dB(A) and 86 dB(A). This also implies that 25% of the sound sample lies between 86 dB(A) and the maximum observed value for that frequency, which is 90 dB(A), with only 25% below 83 dB(A). This implies that more than 50% of the sound sample is above 85 dB(A), therefore warranting the use of HPDs. It is imperative to not only have information of the noise level but also to have information concerning the nature of the noise level. The frequency spectrum of the ambient noise level is described in the next section.

4.1.1.2 Description of the ambient noise spectrum

Noise sources are commonly assessed only in terms of the mean overall noise levels. This does not provide information concerning the frequency distribution and type of noise (being continuous, intermittent, impact, etc.). Knowing the frequency spectrum of the ambient noise, the effectiveness of the Noise Clipper® can be evaluated in terms of the appropriate amounts of attenuation for the frequencies at which the noise is emitted (Steeneken, 2004, p. 2). Attenuation effectiveness per centre frequency has to be described. In order to do this the frequency spectrum of the ambient noise must be known. The frequency spectrum measured in this study is presented in Figure 14.

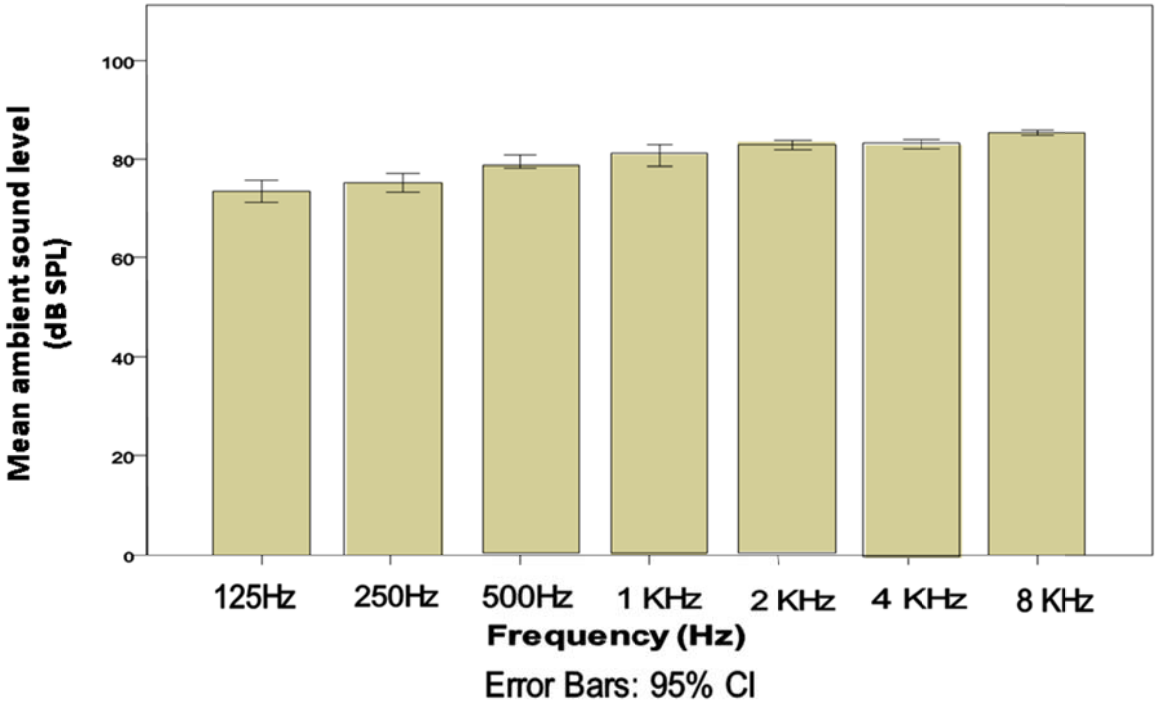

Figure 14. Average frequency spectrum of ambient noise (n=840)

On the vertical axis of Figure 14 the mean ambient noise levels in dB(A) are presented, while the horizontal axis reflects the measured centre frequencies. This figure clearly shows an increase in the observed noise levels with increased frequency. From the data in Table 3 it is clear that the mean value for 125 Hz was 74 dB(A) and 85 dB(A) for 8 kHz. The finding that higher noise levels were measured for high frequencies is significant because the human ear is more susceptible to noise damage in the 3000 Hz, 4000 Hz and 6000 Hz areas (Melnick, 1994, p. 537) and workers should therefore be adequately protected, especially at these frequencies.

Figure 14 shows the 95% confidence intervals as well. Confidence intervals are one way

to represent how good a specific estimate in the sample (for example, the arithmetic mean) is. It is an indication of how sure we are that the mean sound level for that specific centre frequency is the true value for this measurement. Ninety five percent confidence intervals present the boundaries within which we are 95% sure that the true value is located. The larger a 95% confidence interval for a particular estimate, the more caution is required when using the estimate (McDonald, 2009, pp.112-117). It was found that the values for frequencies below 1000 Hz were relatively unstable as a wider 95% confidence interval was found, signifying low frequency noise fluctuation. The smaller 95% confidence intervals obtained for frequencies above 1000 Hz imply that elevated noise levels were measured on all three three days and that they were constantly present at high intensities compared to the lower intensities obtained for the frequencies below 1000 Hz.

The data in Figure 15 are numerically reflected in Table 3. This table, as discussed earlier, presents the mean ambient noise values, in dB(A) and the corresponding spread (or dispersion) expressed by the standard deviation, range, and interquartile range. The mean scores represent a numerical average per centre frequency, measured over three days. The lowest mean noise level measured was 74 dB(A) at 125 Hz while the highest mean noise level was 85 dB(A) at 8000 Hz. The standard deviations for 125 Hz and 8000 Hz are 12 dB and 3 dB respectively, with the large standard deviation for the low frequencies indicating the significant variability in the ambient noise levels for these frequencies. To determine if these differences between the low and high frequencies were statistically significant an analysis of variance (ANOVA) (Leedy & Ormrod, 2005, p. 274) was carried out. With information available on the differences between the measured centre frequencies it was decided to determine what the effect would be of the measurement over the three days. A two-way ANOVA, using day of measurement and frequency as independent variables (Roberts & LLardi, 2003, p. 105), was conducted to determine whether there was a significant difference between the mean noise levels at different centre frequencies over the three different days. The results of this analysis are presented in Table 7.

Table 7 Tests of Between-Subjects Effects - two-way ANOVA

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	24394.181[a]	20	1219.709	30.863	.000
Intercept	5364166.519	1	5364166.519	135731.197	.000
Frequency	13750.364	6	2291.727	57.988	.000
Day	3363.217	2	1681.608	42.550	.000
Frequency* Day	7280.600	12	606.717	15.352	.000
Error	32367.300	819	39.521		
Total	5420928.000	840			
Corrected Total	56761.481	839			

Note: R Squared = .430 (Adjusted R Squared = .416) df=degree of freedom; F=F-ratio; sig=significant effects

A two-way ANOVA with day and frequency as independent variables and the measured ambient noise levels as the dependent variable was used. The results of the ANOVA show that a significant main effect (Roberts & LLardi, 2003, p. 105) was found for both day and frequency and a significant interaction effect for day and frequency (Table 7). The analysis for day of measurement will be discussed in detail in the next section.

Since a highly significant main effect for frequency was observed, indicated by a p-value < 0.0001, a post-hoc analysis was carried out in order to determine which centre frequencies of the ambient noise level were significantly different from each other, measured over three consecutive days. Both the Tukey honestly significant difference and Scheffé post-hoc methods (Roberts & LLardi, 2003, p. 104) revealed that frequencies above 1000 Hz had significantly higher noise levels than frequencies below 1000 Hz. Further evaluations of the ambient noise levels are necessary to determine what the influence of time of measurement on the ambient noise levels might be.

4.1.1.3 The influence of time of measurement on the ambient noise

Because the measurements were conducted over three consecutive days it was essential to determine if inter-day differences in ambient noise levels were present. This was deemed necessary for ascertaining if the Noise Clipper® would be capable in attenuating possible fluctuations in ambient noise levels. The mean ambient noise levels in dB(A) measured per day are depicted in Figure 15.

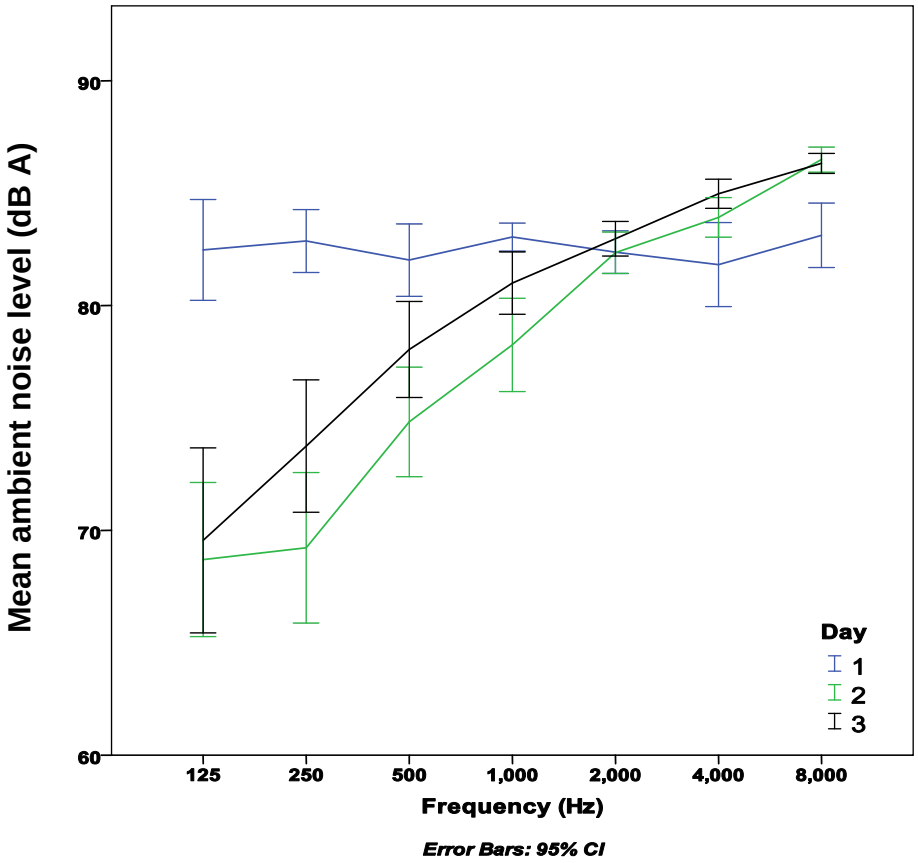

Figure 15. The mean ambient noise levels (dB(A)) per centre frequency per day

In Figure 15 it is clear that there are differences between the three observation days. The results for day one is visually different from the other days since it has a higher low frequency component (below 1000 Hz) than is the case for days two and three. To determine if these differences are statistically significant an analysis of variance (ANOVA) (Leedy & Ormrod 2005, p. 274) was carried out as described above.

From the results of the ANOVA (Table 7) it is clear that a highly significant main effect was also found for day of measurement. This implies that the mean noise levels, measured per day, were significantly different from each day that measurements were conducted. This finding confirms the variations found in ambient noise levels over the three days.

A post hoc analysis (Roberts & LLardi, 2003, p. 105) of the data collected over three days was done to determine if the noise levels between days were statistically significant. Both the Tukey honestly significant difference and Scheffé (Roberts & LLardi, 2003, p. 104) revealed that the means of all noise levels as measured over all three days differed statistically significantly from each other. The significant interaction effect (Frequency* Day) indicated that the difference between different days was also influenced by the centre frequency. Lower

frequencies (below 1000 Hz) showed a significantly different pattern than the higher frequencies. Much greater variability was observed in the lower frequencies, while the frequencies above 1000 Hz showed consistently higher noise levels. This observation is significant in that the high frequency area of the cochlea is the area most susceptible to noise damage. Because this is the frequency area of concern, the attenuation characteristics of the Noise Clipper® needs to be evaluated to determine its effectiveness for these frequencies.

4.1.2 Attenuation characteristics of the Noise Clipper®

In the previous section a description was given of the ambient noise in terms of level, frequency, and time characteristics. In order to evaluate the effectiveness of the Noise Clipper® the attenuation characteristics of the device need to be explored. Different methods exist to evaluate the attenuation abilities of HPDs as described in Chapter 2 of this thesis. The method used in this study was the F-MIRE test protocol. A description of this method, standards, and measurement technique was provided in Chapter 2.

4.1.2.1 Mean attenuation level of Noise Clipper® and its spectral characteristics

The attenuation characteristics of 40 Noise Clippers® worn by 20 different workers were evaluated using the F-MIRE test protocol over three consecutive days in a real world environment. This rendered a total of 120 F-MIRE measurements per centre frequency.

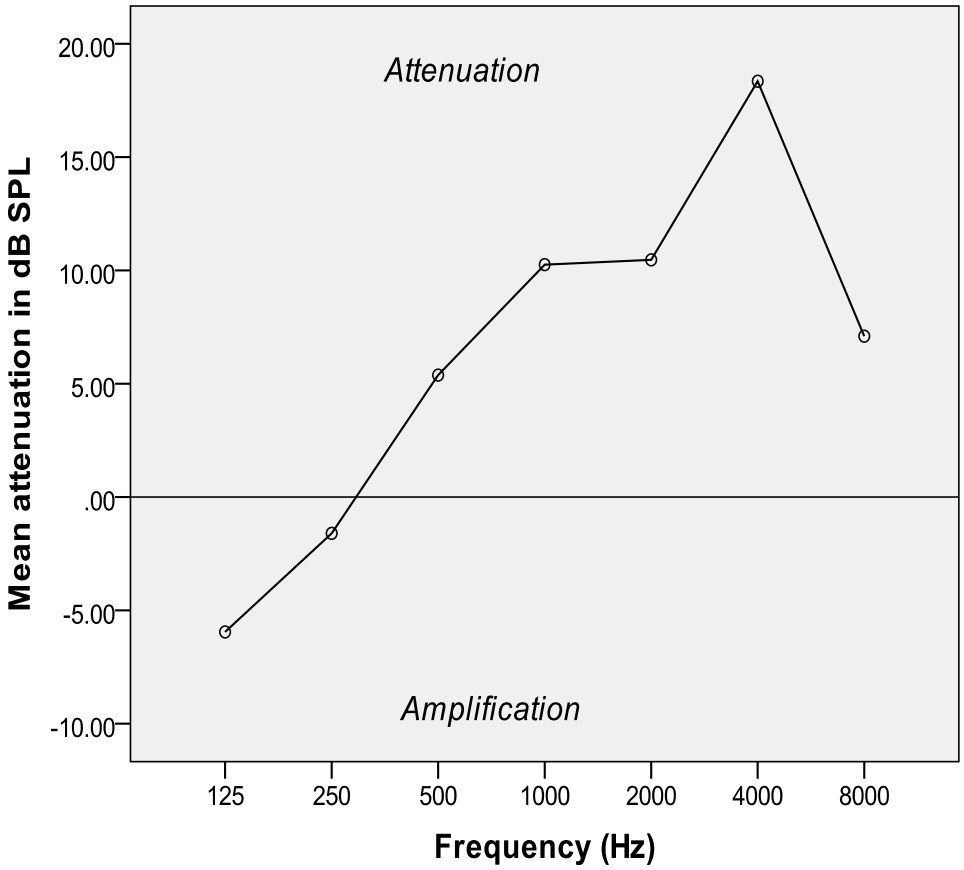

Figure 16. Mean attenuation levels averaged over three days using the F-MIRE test protocol

Figure 16 shows the mean attenuation levels per centre frequency, measured using the F-MIRE test protocol over the three consecutive days. Each centre frequency had 120 measurements. Attenuation is calculated as the difference (in dB) between the output of the reference microphone and the measurement microphone of the F-MIRE probe that was placed in the body of the Noise Clipper®. Positive attenuation values indicate a higher value for the reference microphone, signifying real attenuation, while negative attenuation values signify amplification (Vinck, personal interview, 2012). Figure 16 clearly shows a different trend in attenuation for different centre frequencies. On average, attenuation was observed for all centre frequencies above 250 Hz, while amplification was present at 125 and 250 Hz. A further observation was that, for higher frequencies, larger mean attenuation values were found, except for 8000 Hz. The highest attenuation was measured at 4000 Hz where the ear is most susceptible to noise damage (Mathur & Roland, 2009, p. 1).

The number of measurements, (N), mean attenuation levels, their standard deviations, and ranges (from maximum to minimum) per centre frequency, measured over the three

consecutive days are presented in Table 8.

Table 8 Overall F-MIRE results (average attenuation in dB per frequency band) of the Noise Clipper® (days 1; 2 and 3)

Frequency (Hz)	N	Mean attenuation (dB)	Standard. deviation	Minimum	Maximum
125	120	-5.95	16.61823	-59	23
250	120	-1.6	13.95876	-39	25
500	120	5.3833	11.65699	-33	28
1000	120	10.2583	9.69319	-20	30
2000	120	10.4667	7.663	-23	30
4000	120	18.35	10.85012	-12	44
8000	120	7.1	9.71303	-18	25
Total	840	6.2869	13.92504	-59	44

A total of 840 F-MIRE measurements were made of all the centre frequencies indicated in Table 5. This table confirms the existence of an amplification of the ambient noise of 5.59 dB for 125 Hz and 1.6 dB for 250 Hz centre frequencies. The highest mean attenuation level of 18.35 dB was measured for 4000 Hz. The standard deviations for frequencies below 1000 Hz were higher than for frequencies above 1000 Hz with the smallest standard deviation found for 2000 Hz. The higher standard deviations for the low frequencies once again confirmed the higher variability found in the attenuation ability of the Noise Clipper® for lower frequencies.

A one-way ANOVA (Roberts & LLardi, 2003, p.102) was performed to evaluate if the mean attenuation values (Table 8) observed between the different centre frequencies were significantly different from each other. Frequency was used as the independent variable and attenuation (in dB) as the dependent variable for the analysis. The results are presented in Table 9.

Table 9 Difference in attenuation characteristics between the different frequencies (one way ANOVA results)

Attenuation	Sum of Squares	df	Mean square	F	Sig.
Between groups	47062.031	6	7843.672	56.508	.00001
Within groups	115625.825	833	138.807		
Total	162687.856	839			

Note: df =degrees of freedom; F= F-ratio; Sig.=Significant effects.

A highly significant difference was observed ($p < 0.0001$) between the mean attenuation values of the different centre frequencies. Since the ANOVA analysis does not indicate where these differences are, a post-hoc analysis was performed.

Applying the post-hoc Scheffé method (Roberts & LLardi, 2003, p. 109) it became clear that the attenuation level at all the frequencies measured over the three days differed significantly from each other, except those measured at 125 Hz and 250 Hz. This signifies that the observed trend of higher attenuation values for higher frequencies is real and cannot be attributed to chance. With the information of the attenuation ability of the Noise Clipper® known, the consistency and nature of the attenuation over time was also evaluated.

4.1.2.2 The influence of time of measurement on the attenuation level

The previous section described the trend in attenuation levels per centre frequency. It became clear that the Noise Clipper® attenuation was greater in the higher frequencies. The question remains whether this attenuation pattern is consistent over time and if this trend can be reproduced over three consecutive measuring days. In other words, what is the attenuation stability of the HPD?

In order to answer this question a correlational analysis was carried out on the observed F-MIRE data. A two-tailed Pearson-*r* product-moment correlation coefficient (Welkowitz, Ewen & Cohen, 1998, p. 175) was calculated. The results of this analysis are displayed in Table 10.

Table 10 Correlations between the attenuation levels measured over the three days

		Day 1	**Day 2**	**Day 3**
Day 1	Pearson correlation	1	.193**	.240**
	Sig. (two-tailed)		.001	.000
	N	280	280	280
Day 2	Pearson correlation	.240**	1	0.000
	Sig. (two-tailed)	.000		
	N	280	280	280
Day 3	Pearson correlation	.193	.721**	1
	Sig. (two-tailed)	.001	.000	
	N	280	280	280

*Note:** Correlation is significant at the 0.01 level (2-tailed); Sig.=significance; N=sample size.*

A Pearson-*r* correlation coefficient (Welkowitz, Ewen & Cohen, 1998, p. 175) was calculated between the data of the different measurement days. A perfect match between the different days would show a coefficient of 1.0. When there is no correlation at all a coefficient will be 0.0. Statistically significant correlations were found between all measurements over the three days ($p < 0.01$), indicating that these data are related to each other. The strength of this relationship as indicated by the value of the coefficient was not the same for all three days; however, the measurements for day two and three were much closer related ($r = .721$) than those for day one and day two ($r = .240$), and day one and day three ($r = .193$).

The results of the Pearson-*r* correlation analysis confirm that the attenuation pattern found for day one differed significantly from the results for day two and day three. It is therefore evident that the attenuation results of the Noise Clipper® as measured over three days were unstable. This instability of the obtained attenuation results is further illustrated in Table 11.

Table 11 The absolute average difference in attenuation across frequencies between day one and day two and day two and day three

Frequency (Hz)	Day1-Day2	Day2-Day3
125	10.475	0.475
250	10.3	5.975
500	2.1	4.525
1000	0.4	3.65
2000	3.625	2.325
4000	3.375	4.575
8000	8.525	1.15
Mean	5.5428571	3.23929

The absolute average difference in attenuation levels across frequencies between day two and day three was calculated as 3.24 dB (range across frequencies is 0.475 – 5.975 dB), whereas the average difference in attenuation was calculated as 5.54 dB between day one and day two (range across frequencies is 0.4 – 10.475 dB). These findings indicate that, although smaller differences were found between day two and day three, inconsistencies were found for every day that measurements were made. A graphical representation of these data is presented in Figure 17.

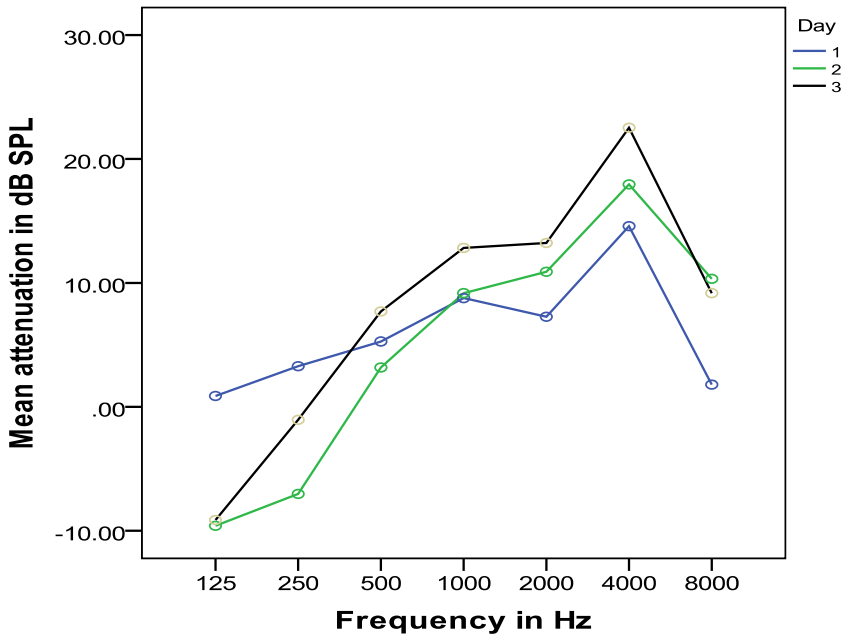

Figure 17. The F-MIRE attenuation results of the Noise Clipper® (average attenuation in dB per frequency band) measured per day

From this graph in Figure 17 it is apparent that there is a significant increase in attenuation (in dB) over the three days, except for the lower frequencies (< 1000 Hz). In addition, the lower frequencies (125 Hz and 250 Hz) show a significantly lower attenuation for day 2 and 3 than for day 1. The ideal device should attenuate in a linear way and attenuation should remain constant over the different days. The data above clearly demonstrate that this is not true for the measurements made in this study.

4.1.2.3 Attenuation characteristics of Noise Clipper® evaluated by F-MIRE versus REAT

In the sections describing the ambient noise levels and the attenuation characteristics above, data presented were obtained using the F-MIRE test protocol. However, the REAT method is still referred to as the golden standard (Berger, 2007, p. 1). The frequency-specific REAT attenuation levels provided by the manufacturer were directly compared with the frequency-specific attenuation measurements obtained in this study, using the F-MIRE test protocol; this information is presented in presented in Figure 18.

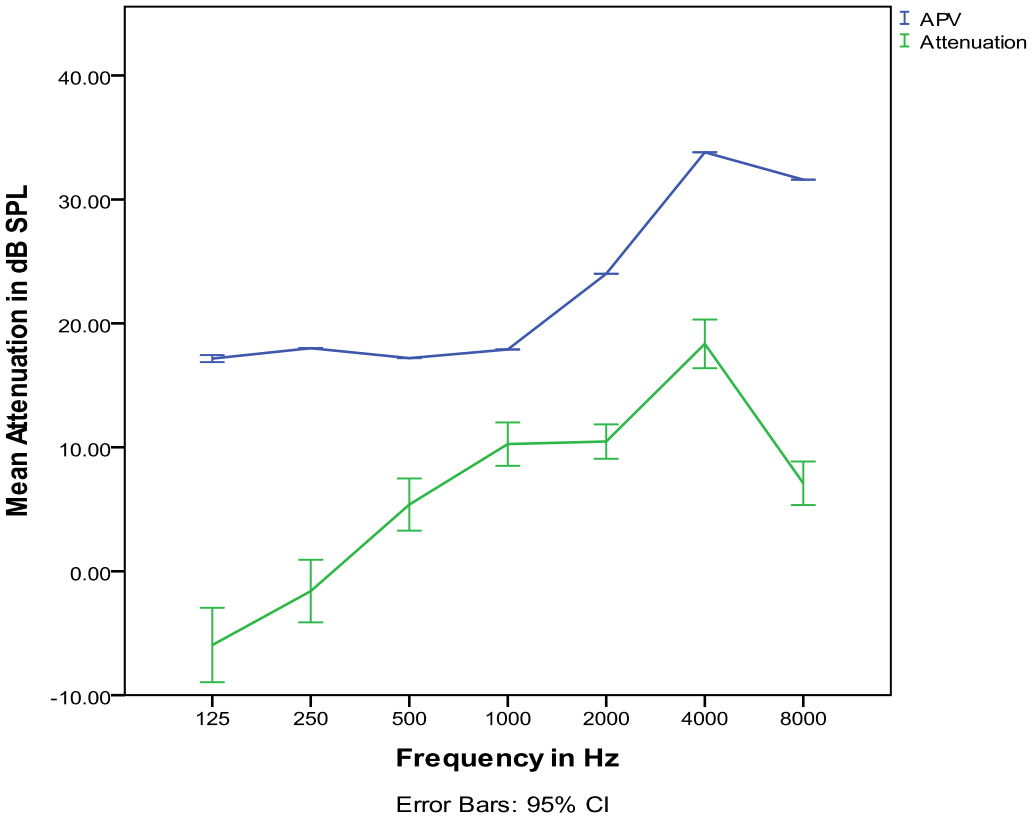

Figure 18. The mean attenuation values of the Noise Clipper® as measured by the manufacturer specified REAT and F-MIRE. (APV = REAT, top, Attenuation = F-MIRE, bottom)

In Figure 18 the data distribution of the frequency specific attenuation levels of the Noise

Clipper® are presented for both the REAT and the F-MIRE test protocols. The bottom line represents the mean F-MIRE attenuation data and the top line the REAT (assumed protection value) attenuation data. It is clear that the F-MIRE is far below the REAT data for all the centre frequencies. This indicates a possible over estimation of the attenuation ability of the Noise Clipper® should the REAT results be used.

The mean F-MIRE result per centre frequency as measured over three consecutive days and the mean assumed protection value of the REAT as supplied by the Noise Clipper® manufacturer is presented in Table 12.

Table12 Frequency specific F-MIRE versus REAT attenuation levels

Frequency in Hz	N	Mean-F MIRE	Mean assumed protection value REAT	Difference in Attenuation (REAT-F-MIRE)
125	120	-6.95	17.2	23.1
250	120	-1.6	18	19.6
500	120	5.38	17.2	11.8
1000	120	10.25	17.9	7.7
2000	120	10.47	24	13.5
4000	120	18.35	33.8	15.5
8000	120	7.1	31.6	24.5

Note: N=sample size; assumed protection value (APV) = A prediction of the noise reduction possible to achieve in real use, usually calculated as the mean attenuation minus one standard deviation.

In Table 12 the differences between the F-MIRE and REAT attenuation results are shown. The N value of 120 represents the number of measurements made per centre frequency on 40 ears measured over three consecutive days (for the F-MIRE measurements). The differences between the F-MIRE and REAT results per centre frequency are reflected in the last column of Table 9. On average, the F-MIRE method predicted a significantly smaller attenuation of 16.5 dB than the REAT method across all frequencies. The biggest differences were calculated at 125 Hz and 8000 Hz, where it was found to be 23.1 dB and 24.5 dB respectively. The smallest difference of 7.7 dB was found at 1000 Hz.

Though significant differences were found, the question remained whether measurements obtained for both methods (F-MIRE versus REAT) were related. In order to answer this

question, a Pearson-*r* correlation coefficient (Welkowitz, et al., 1998, p. 175) was calculated between the F-MIRE and REAT attenuation data. The pertaining results are presented in Table 13.

Table 13 Correlation between F-MIRE and REAT attenuation results

		F-MIRE Attenuation	**REAT attenuation**
Attenuation	Pearson correlation	1	.393**
	Sig. (two-tailed)		0.001
	N	840	840
REAT	Pearson correlation	.393**	1
	Sig. (two-tailed)	0.001	
	N	840	840

*Note: ** Correlation is significant at the 0.01 level (2-tailed); Sig.= significance; N= sample size.*

A two tailed Pearson-*r* correlation analysis (Welkowitz, et al., 1998, p. 175) was done between the assumed protection value (assumed protection value-REAT results) of the Noise Clipper® and the F-MIRE attenuation results to determine if a significant correlation existed between these two measuring protocols and to determine the extent to which the values of the two variables are related. From the data in Table 13 it is clear that a significant, though moderate, correlation was present (.393), which indicated that both techniques were clearly producing related results that do not explain all of the variances. Figure 18 visually demonstrates that both methods measured less attenuation in the lower frequencies and more attenuation in the higher frequencies. The greatest difference between the two methods was found in the overall attenuation values. The REAT results indicate much higher attenuation than the results for the F-MIRE measurement.

4.1.3 Evaluation of effectiveness of the Noise Clipper®

The attenuation and spectral characteristics of the Noise Clipper® were discussed in the previous sections. To assess the effectiveness of the Noise Clipper® the attenuation results have to be compared to the South African legal limit of 85 dB(A) (SANS 10083, 2004, p. 9).

4.1.3.1 Effectiveness compared to South African legal criteria

The results of the two different attenuation protocols, F-MIRE and REAT, were compared to the

South African legal limit of 85 dB(A) (SANS 10083: 2004 p. 9).

4.1.3.1.1 F-MIRE test protocol

In order to determine the effectiveness of the Noise Clipper® in the workshop, the residual noise levels (calculated as the difference between the mean ambient noise level at a specific centre frequency minus the mean attenuation level in dB at the same frequency obtained by the F-MIRE method), were compared to the South African legal limit of 85 dB(A) described in SANS 10083:2004, p. 9. In Table 14 the degree of effective attenuation is expressed in percentiles. This table shows that 88% of the measurements implies effective protection by the Noise Clipper®, as indicated by a protection value lower than 0 dB, while 12% of the measurements indicated insufficient protection according to the South African legal limit of 85 dB(A) (SANS 10083: 2004, p. 9).

For comparison purposes between the F-MIRE and REAT attenuation results, Tables 14 and 15 are placed alongside each other.

Table 14 Percentiles for attenuation effectiveness: F-MIRE results compared to the South African legal limits 85 dB(A), (N=840)

Percentile rank	dB (SPL)
25	-18.0000
50	-12.0000*
75	-5.0000
80	-3.0000
85	-1.0000
86	.0000
87	.0000
88	.0000
89	1.0000
90	1.0000
95	6.0000
99	14.0000

*Note: * Denotes median*

Table 15 The percentiles for attenuation effectiveness: REAT results compared to the South African legal limits 85 dB(A)

Percentile rank	dB (SPL)
25	-33.8000
50	-27.0000*
75	-22.0000
80	-20.9000
85	-19.9000
86	-19.9000
87	-19.3000
88	-19.2000
89	-18.9000
90	-18.2100
95	-16.0000
99	-12.3000

*Note: * Denotes median*

A visual presentation of the findings in Table 14 is presented in Figure 19 while the visual presentation of the findings in Table 15 is presented in Figure 20.

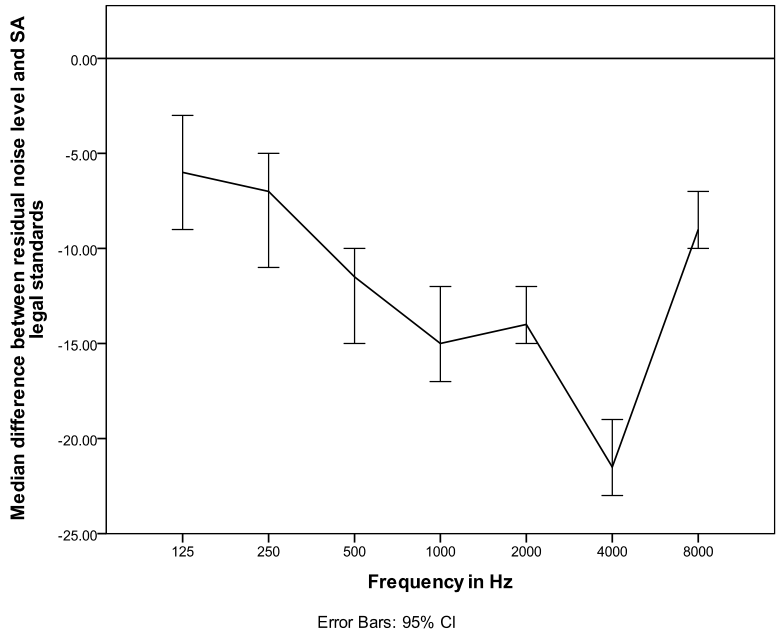

Figure 19. The median difference between the residual noise levels and the requirements stipulated in SANS 10083 (2004, p .9) using the F-MIRE test protocol

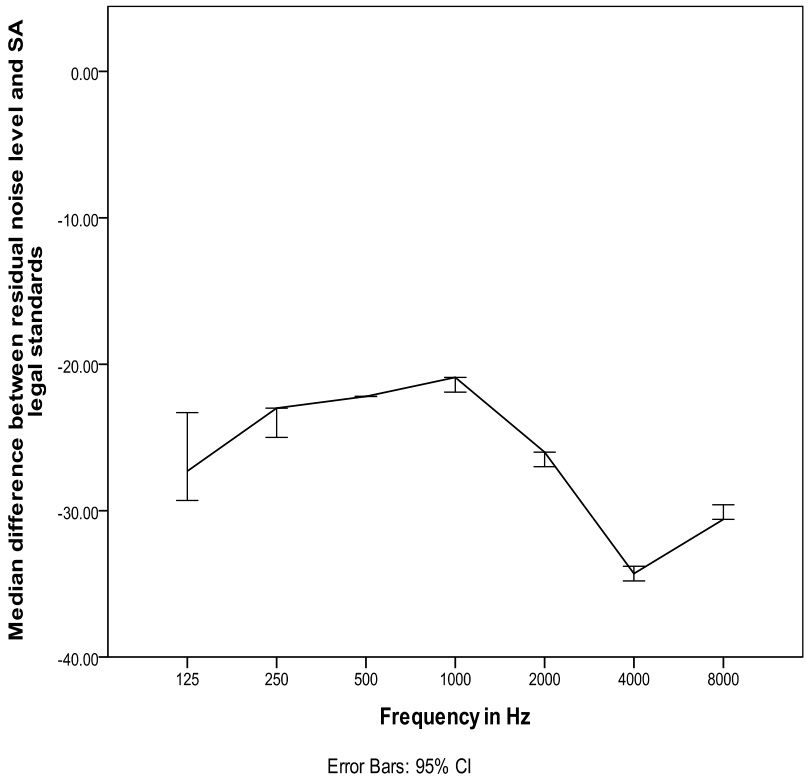

Figure 20. The median difference between residual noise levels and the assumed protection values of the Noise Clipper®, obtained by using the REAT test protocol, at different centre frequencies.

Figure 19 shows the median difference between the residual noise level and the legal South

African (SANS 10083:2004, p. 9) limit for different centre frequencies. A negative value indicates that the legal limit is not exceeded, while a positive value proves the opposite. The median 50% population, wearing the Noise Clipper®, will be adequately protected in terms of to the South African legal limit of 85 dB(A) (SANS 10083:2004, p. 9). However, though this is true for the median worker in the workshop, not all participants in this study received the same degree of protection.

4.1.3.1.2 REAT test protocol

The previous section described the effectiveness of the Noise Clipper® based on the MIRE attenuation results, which is a new method of measurement. This section determines the effectiveness of the Noise Clipper® based on the "golden standard" (Berger, 2005, p. 1) method also referred to as the REAT test protocol.

Residual noise levels, calculated as the difference between the mean ambient noise level at a specific centre frequency minus the mean assumed protection value in dB at the same frequency obtained by the REAT method, were compared to the South African legal limit of 85 dB(A) described in SANS 10083:2004, p. 9. The assumed protection values at the individual centre frequencies of the Noise Clipper® were provided by the manufacturer (Pretorius, personal interview, 2009). The results of this analysis are reflected in Table 15 (above). Table 15 shows that using the REAT data as a reference, all participants were sufficiently protected against NIHL (a protection value below 0 dB is indicative of effective protection). This is in contrast with earlier findings using the F-MIRE attenuation results where only 88 % of measurements implied adequate protection. A visual presentation is given in Figure 20 that shows the median difference between the residual noise level and the South African legal limit (SANS 10083:2004, p. 9) for different centre frequencies. Negative values indicated that the legal limit was not exceeded, while positive values proved the opposite.

In Figure 20 (refer to p. 76) the zero line represents the South African legal limit of 85 dB(A) The measured REAT values are far below the zero line for all centre frequencies indicating that, on average, according to this means of assessment all workers were adequately protected. Comparing Figures 20 and 19 it is obvious that, using the REAT method, far better protection is predicted than using the data from the F-MIRE protocol.

Taking into account the results of the F-MIRE and REAT attenuation data as compared to the South African legal limit a further aim of the study was to evaluate the attenuation data against the BT for TTS as described by Mills and Going (1982, p. 119).

4.1.3.2 Effectiveness of the Noise Clipper® attenuation results compared to the BT for TTS

A comparison was made to determine if the Noise Clipper® attenuated noise below the BT for TTS. The South African legal limit is presented as a single value of 85 dB(A) that signifies that, for protection against NIHL, the noise levels should be below this limit. However, Mills and Going (1982, p. 119) found that for each centre frequency the human ear responded in a different manner to different sound levels. They indicated, for example that the BTs centred at 4000 Hz is 74 dB SPL, 78 dB SPL for 2000 Hz, 82 dB SPL for 1000 Hz and 500 Hz (Mills & Going, 1982, p. 119). In this study the comparison was made to determine if the Noise Clipper® attenuated noise below the BT for TTS as described by Mills and Going (1982, p. 119). The results are presented in Table16.

Table 16 Distribution of the differences between the BT for TTS and the residual noise levels based on the F-MIRE test protocol, expressed in percentiles (n = 840)

Percentile rank	dB (SPL)
25	-16.0000
50	-9.0000*
75	-3.0000
80	-1.0000
85	-1.0000
86	.0000
87	.0000
88	1.0000
89	1.0000
90	3.0000
95	7.0000
99	14.0000

*Note: * Denotes median*

A breakdown of the results in terms of the risk for developing NIHL for low (125 HZ and 250 Hz), middle (500 Hz, 1000 Hz, and 2000 Hz), and high (4000 Hz and 8000 Hz) frequencies indicated that, of the measurements made, 10.5% was not well protected for the low frequencies, 16.0% for the middle frequencies, and 25% for the frequencies above 2000 Hz. This illustrates that the highest risk for developing NIHL was for the highest frequencies.

The median difference between the residual noise levels and BT for TTS using the F-MIRE test protocol is further reflected in Figure 21.

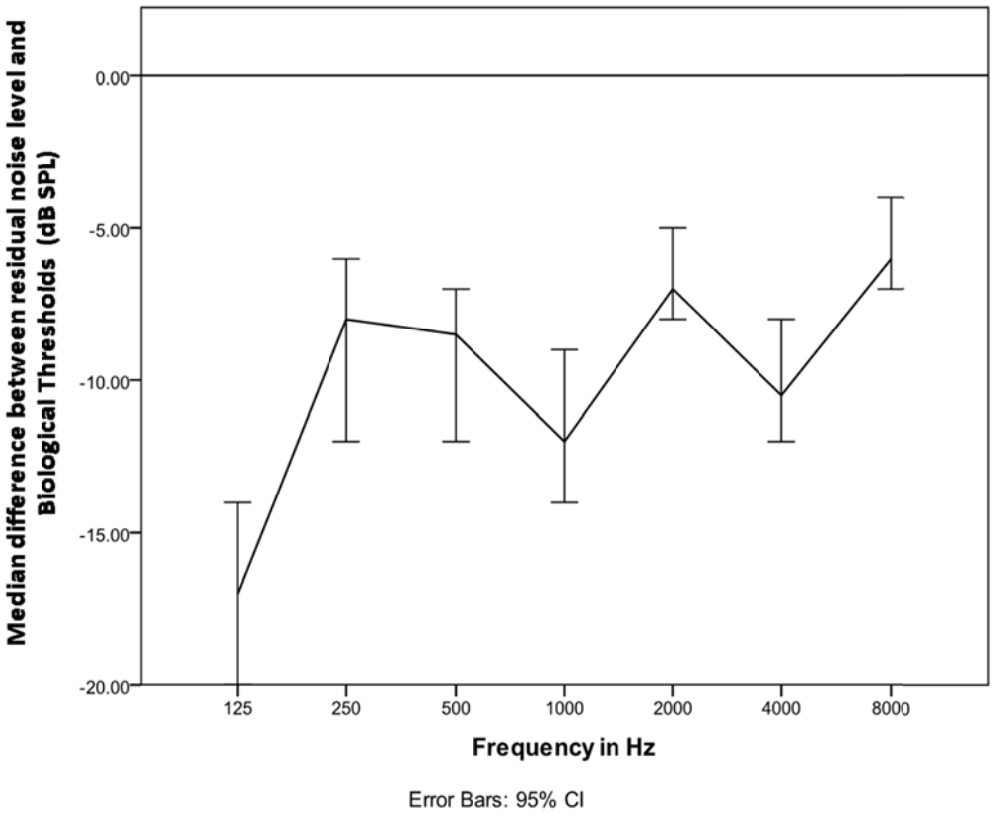

Figure 21. Median difference between the residual noise levels and BT for TTS using the F-MIRE test protocol

The data in Figure 21 show once again that adequate protection is provided as reflected by the median measurements made in this study. This is indicated by the attenuation values per centre frequency that are below the zero line. However, with the more detailed analysis of each individual measurement found in the percentiles of Table 16, it is demonstrated that across frequencies 87% (of the measurements) were well protected, but 13% were still at risk of developing NIHL exceeding the BT for TTS between 1 and 14 dB. Examining the frequencies where this risk is greatest, data indicated that the highest risk can be found for the 4000 Hz and 8000 Hz frequencies.

In describing the effectiveness of the Noise Clipper® the first phase of the study was to describe the characteristics of the ambient noise in the workshop, the influence of centre frequency (spectral composition) and day of measurement of observed noise levels as well as the actual attenuation effectiveness of the Noise Clipper®. This was done by comparing the ambient noise characteristics to the attenuation characteristics, as measured by the F-MIRE test protocol.

Beyond the aspects mentioned above (attenuation effectiveness), there are additional key

parameters that determines the effectiveness of a HPD. Acoustic attenuation characteristics are not the only way to protect the worker against noise damage. Arezes and Miguel (2002, p. 532) described other equally important ergonomic features that should be taken in to account such as comfort, need for verbal communication, auditory signal detection, compatibility with other safety equipment, durability and maintenance. These aspects can influence the workers' perceived comfort and lead them to either use it consistently or be dissatisfied and, consequently, misuse the device, which may drastically alter the attenuation effectiveness afforded by the device. The second phase of this study was to evaluate the subjective comfort levels afforded by the Noise Clipper® by using a bi-polar comfort rating scale. The results will be discussed in the following section.

4.2 Subjective evaluation of the Noise Clipper® CHPD

In the studies of Arezes and Miguel (2002, p. 534) and Park and Casali (1991, p. 159) on comfort evaluation of HPDs, correlations were made between the different sub-scales and the centre scale being the comfortable-uncomfortable scale. In the present study all sub-scales were treated as significant and were included in the results of the descriptive statistics presented in Table 17.

Table 17 Results of the comfort evaluation of the Noise Clipper®

		Painless-Painful	**No pressure - Pressure**	**Hard-Soft**	**Cold-Hot**	**Smooth-Rough**	**Good fit-Poor fit**	**Open-Closed**
N Valid		215	215	215	215	215	215	215
N Missing		0	0	0	0	0	0	0
Median		1	1	7	4	1	1	3
Minimum		1	1	1	1	1	1	1
Maximum		7	7	7	7	6	7	7
Percentiles	25	1	1	3	2	1	1	1
	50	1	1	7	4	1	1	3
	75	1	1	7	4	1	1	7

		Ear empty–Ear full	**HOURS**	**Comfortable-Uncomfortable**	**Tolerable-Intolerable**	**Isolation-No isolation**	**Simple to fit-Complicated to fit**	**Light-Heavy**	**Tight - loose**
N Valid N		215	215	215	215	215	215	215	215
N Missing		0	0	0	0	0	0	0	0
Median		1	8	1	2	4	1	1	7
Minimum		1	2	1	1	1	1	1	1
Maximum		7	8	7	7	7	7	7	7
Percentiles	25	1	8	1	1	1	1	1	7
	50	1	8	1	2	4	1	1	7
	75	4	8	1	1	7	1	1	7

In Table 17 the n-value was 215. Two hundred and forty five subjects were interviewed. Although the researcher conducted the survey personally some subjects chose not to respond to certain of the questions. It was decided to exclude the incomplete questionnaires from the statistical analysis resulting in a total of 215 questionnaires used.

The subjects' responses were recorded on the rating scale and a numerical value assigned, ranging from one to seven. For each sub-scale, the response most closely related to the right adjective was coded seven and the most closely related to the left adjective was coded one. The sub-scales items presented in Table 17 highlight some of the most important comfort aspects of the Noise Clipper® after reverse coding were applied as were describe in the methodology section. The wearing of the Noise Clipper® was perceived by 75% of the subjects as painless with a descriptor value of one, where it was perceived as hard the descriptor value was seven. Further observations in Table 17 is that although it is made of a hard acrylic material, it is perceived as "smooth" with "no pressure" and "tight" but "tolerable" as the descriptor values were one. Seventy five percent of the subjects indicated that the Noise Clipper® was neither perceived to be "hot" or "cold" and neither "empty" or "full". Indicated by the percentile values (25%, 50% and 75%) more than 75% of the subjects (Table 17) indicated that the Noise Clipper® was comfortable to use and easy to fit (numerical value-1).

In order to ensure that a high efficacy of attenuation is achieved by a HPD, it is imperative to know how long during an eight hour work shift a worker uses the device without removing it (Arezes & Miguel, 2002, p. 532).

4.3 The reported wearing time of the subjects using the Noise Clipper®

The percentage hours during which the HPD is worn (during an 8-hour work shift) will have an effect on its attenuation effectiveness. If the device has a noise reduction rating of 25 dB(A), it would be 100% effective if worn for a full 8-hour work shift. If, for example, the device is removed for 15 minutes, the noise reduction rate will fall to 20 dB(A) (Vinck, 2007, p. 19). It is therefore extremely important that the worker should use the protective device willingly and consistently for a full eight hour work shift (Behar, 2007, p. 2; Hiselius & Berg, 2007, p. 2; Park & Casali, 1991, p. 152). The results of the self reported wearing time is given in Table 18.

Table 18 Frequency procedure of the percentage self-reported wearing-time

Hours worn	**Frequency N= 236**	**Percentage**	**Cumulative frequency**	**Cumulative percentage**
2	2	0.85	2	0.85
4	9	3.81	11	4.66
6	38	16.1	49	20.76
8	187	79.24	236	100
Frequency missing = 9				

In Table 18 the first column represents the time intervals that the Noise Clipper® was worn during an eight hour work shift. The second column indicates the number of subjects per time interval with a total of 236, while the third column presents a percentage breakdown of the responses. The last two columns represent the frequency counts and are expressed in terms of frequencies (absolute numbers) and percentages. The cumulative frequency corresponds to a particular value that is the sum of all the frequencies (all the responses) up to and including that value (StatTrek, 2010, p.1). The cumulative frequency is a recalculation of the percentages (percentage breakdown of the responses) after the missing data (subjects not responding to this question) was subtracted. From this data, it is evident that 79.2 % of the subjects (187) indicated that they used the Noise Clipper® for a full eight hour work shift, 16% (38) of the subjects used it for six hours, 3.8% (9) for four hours, and merely 0.85 % (2) for two hours. At the bottom of Table 18 the frequency missing is nine, indicating the number of subjects who did not complete this part of the questionnaire. From the data (Table18) it is clear that 20% of the subjects did not wear the Noise Clipper® for a full eight-hour work shift and will therefore be at risk for developing NIHL.

4.4 Summary

The effectiveness of the Noise Clipper® and the characteristics of the existing ambient noise levels in a workshop of the Rustenburg division of Impala Platinum were measured and described. These characteristics included the overall ambient noise level which was measured at 80.55 dB(A) with the maximum observed levels ranging between 88 dB(A) and 95 dB(A) for all centre frequencies. A description of the noise spectrum revealed that higher noise levels were measured for the high frequencies. A further observation was the influence of time of measurement on the ambient noise levels. Significant differences between the three consecutive days were found, confirming that

fluctuation in ambient noise levels is present in the workshop of Impala Platinum Rustenburg.

The actual attenuation of the Noise Clipper® revealed that, on average, attenuation was observed for all centre frequencies above 250 Hz, while amplification was present at 125 Hz and 250 Hz. It was further found that the higher frequencies presented with larger mean attenuation values, except for 8000 Hz. The highest attenuation was measured at 4000 Hz where the ear is most susceptible for noise damage (Mathur & Roland, 2009, p. 1). The results of the F-MIRE attenuation measurements were compared to the manufacturer supplied REAT and the South African legal limit of 85 dB(A). It was found that 88% of the measurements indicated effective protection by the Noise Clipper®, using the F-MIRE results. According to the REAT measurement all (100%) of the study sample will be protected. The same F-MIRE results were compared to the BT for TTS which demonstrated that across frequencies 83% of the measurements indicated protection, but 17% of the measurements indicated a risk for developing NIHL, exceeding the BT for TTS shift with between 1 and 14 dB.

The results of the bi-polar comfort rating scale showed that 75 % of the subjects found using the Noise Clipper® comfortable. From the results of the self-reported wearing time it became evident that 79.2 % of the subjects (187) indicated that they used the Noise Clipper® for a full eight hour work shift, 16% (38) of the subjects used it for six hours, 3.8% (9) for four hours, and merely 0.85 % (2) for two hours. A total of 20, 8% of the subjects did not use the Noise Clipper® for a full eight hour work shift.

A discussion of the results will follow in the next section.

Chapter 5

Discussion of results

5.1 Discussion of the effectiveness of the Noise Clipper®

The main aim of the study was to evaluate the effectiveness of the Noise Clipper® CHPD worn by a group of workers in a workshop of the Implats mine in Rustenburg. The purpose of this chapter is to discuss the results presented in Chapter 4.

The results of the F-MIRE measurements are discussed in the next section.

5.1.1 Characteristics of ambient noise.

The characteristics of the ambient noise are described in relation to the noise level, the noise spectrum and the influence of time of measurement on the ambient noise.

5.1.1.1 Description of the ambient noise level in the workshop.

The overall ambient noise level, across frequencies, was found to be below the South African legal limit of 85 dB(A) (SANS 10083:2004). It was calculated as 80.55 dB(A) with a standard deviation of 3.54 dB. Some measure of variability was found, indicating that the maximum observed levels ranged from 88 dB(A) to 95 dB(A) for all centre frequencies. In Table 3, the data analysis of ambient noise levels measured in the workshop revealed that fluctuations below and above 85 dB(A) were constantly present over the three days and that they were not constant.

Should conventional measurements of ambient noise be made using a strategically placed microphone in the workshop the results may differ from the findings in the present study, the reason being that spherical or plain sound waves are distorted by the human head, the pinna, shoulders and to a lesser extent by the torso. The result of these distortions is that the sound signal at both ears shows characteristic differences in their amplitude and phase spectrum, with the lateral sound incidence of one ear being in the shadow of the head and the other ear not (Kuttruff, 2000, p. 22). This head-shadow effect is a reality in the F-MIRE test protocol for the present study because the reference microphone is in the probe that is inserted into the body of the Noise Clipper®. For this reason the results of the measurement of ambient noise using the IE-33 analyser opposed to conventional methods for noise measurement may differ. This was not considered to alter the validity of the measurements made in this study as the intention was to measure attenuation effectiveness in real world situations using human heads as opposed to non-human acoustic test fixtures or manikins like the KEMAR.

Variation and fluctuations of ambient noise levels are typical of workshop noise activity where variations are found depending on the specific equipment being used (Noise Pollution

Clearinghouse, 1995, p. 1). Durkt (1998, p. 11) measured real world ambient noise levels generated by different types of equipment used for different types of applications and occupations in the mining industry. In this study tape recordings were used to evaluate ambient noise levels. It was reported that noise fluctuations were present which were ascribed to specific equipment being used during the measurements.

The noise exposure levels (ambient noise) measured in the present study indicated that Impala Platinum mine needs to maintain their current hearing conservation program using HPDs until ambient noise levels are successfully lowered to below the South African legal limit of 85 dB(A) (SANS 10083:2004).

A further characteristic of the noise levels that were examined in this study is the spectrum of the noise, which is discussed in the following section. In conclusion, it can be said that the ambient noise levels (80.55 dB(A)) were below the South African legal limit of 85 dB(A), however ambient noise levels measured in the workshop revealed that fluctuations below and above 85 dB(A) were constantly present over the three days and that these levels were not constant.

5.1.1.2 Description of the ambient noise spectrum

For the evaluation of the attenuation effectiveness of the Noise Clipper® devices the frequency spectrum of the ambient noise was measured and described. The data in Figure 15 shows an increase in the observed noise levels with an increase in frequency. The mean noise level measured for 125 Hz was 74 dB(A) and 85 dB(A) for 8000 Hz. It was found that the values for frequencies below 1000 Hz were relatively unstable since a wider 95% confidence interval was found that signified low frequency noise fluctuation. The smaller 95% confidence intervals indicated for frequencies above 1000 Hz implies that elevated noise levels were measured on all three days and that they were constantly present at high intensities. The standard deviations for 125 Hz and 8000 Hz are 12 dB and 3 dB respectively, with the larger standard deviation for the low frequencies, indicating the significant variability in the ambient noise levels for these frequencies. In Figure 16, the fluctuations seen between the three days can be attributed to typical workshop activities where machine maintenance was done. This is evident for days two and three where some machines in the workshop were non-operational for maintenance work. In Figure 15 the narrow 95% comfort index for the high frequencies confirms that irrespective of the machine shut down experienced during days two and three, high frequency noise was constantly measured at elevated noise levels

These findings emphasize the fact that even though machine maintenance was done in the

workshop (were frequencies below 1000 Hz were measured at lower intensities), workers needed to use the Noise Clipper® consistently because elevated high frequency levels were always present. Stable and consistent attenuation of these high frequencies is thus required from the Noise Clipper®. The attenuation effectiveness of the device is discussed later in this chapter. As the measurements were made over three consecutive days it was necessary to determine what the influence of time would be on the ambient noise levels in the workshop.

5.1.1.3 The influence of time of measurement on the ambient noise level

The frequencies above 1000 Hz demonstrated consistently higher noise levels. According to Schophaus (personal interview, 2009) machine maintenance is an on-going necessity in workshops at Impala Platinum mine. He informed the researcher that some of the conveyer belts needed maintenance and that these conveyer belts were non-operational during day two and day three when F-MIRE measurements were made. The result of the conveyer belt shutdown on ambient noise levels can be seen in Figure 16, demonstrating that it had a large low frequency component compared to the results obtained on days two and three. This implies that for days two and three lower noise levels in the low frequencies were measured compared to day one. The results of the two-way ANOVA (Table 16) confirmed that there was a statistically significant difference (p-value < 0.0001) in noise levels between the three days, even between day two and day three. These findings could imply that either the noise levels in the workshop are never constant or that the measuring instrument is unstable.

Durkt (1998, p. 18) measured the noise levels emitted by different pieces of equipment used in the mining industry and suggested that by determining the C-weighted and A-weighted values for a particular piece of equipment the frequency content can be described sufficiently. He found, for instance, that diesel engines generated dominant low frequency noise while drilling equipment generated high frequency noise due to the drill steel impacting on internal chuck assemblies. From the study of Durkt (1998, p. 18) it is clear that different pieces of equipment generates different types of noise causing noise levels and noise spectrums to vary from day to day. This is evident when maintenance is done and some of the equipment is switched off. It is also consistent with the findings of the present study. Because of the uncontrolled fluctuations in noise spectrums in the workshop the Noise Clipper® needs to attenuate all frequencies to levels below the South African legal limit of 85 dB(A) (SANS 10083:2004).

5.1.2 The attenuation characteristics of the Noise Clipper®

With the results of the level, frequency and time characteristics of the ambient noise levels the attenuation effectiveness of the Noise Clipper ® was evaluated. F-MIRE measurements were made on 40 Noise Clippers® worn by 20 subjects with a total of 120 measurements per centre frequency and a combined total of 840 measurements. The attenuation effectiveness was described in terms of the spectral characteristics; the influence of time of measurement on attenuation ability; characteristics evaluated by the REAT and F-MIRE test protocols and a comparison was made to the South African legal limit (SANS 10083:2004) and the BT for TTS.

5.1.2.1 Mean attenuation level of the Noise Clipper® and its spectral characteristics

These measurements were made to quantify the subject's noise exposure and determine the risk of developing NIHL. The results of the attenuation data analysis indicated that the Noise Clipper® attenuated sound more in the higher frequencies and that the noise levels were also found to be higher in the high frequencies. A typical characteristic of NIHL is that the high frequencies are mostly affected by high intensities in these frequency areas. These results signified that the higher attenuation values found for the higher frequencies were significant and could not be attributed to chance.

It is said that sound energy causes the ear protector to vibrate so that it becomes a secondary source of sound that reaches the ear canal. Vibration of HPDs is due to the flexibility of the tissue in the ear canal. This vibration limits the amount of low frequency noise that can be attenuated (Lee, 2011, p. 76). Durkt (1998, p. 18) remarked that lower frequencies are not as easily attenuated because of inherent physical characteristics such as frequency wavelength and construction materials of HPDs. Chasin (2007, p. 1) explained that "Higher frequency sound energy is more easily obstructed than lower frequency sound energy" because it is directly related to the wavelength of the sound. The shorter wavelengths found for high frequencies are more easily obstructed "simply because the obstruction will be a greater proportion of a shorter higher-frequency wavelength" Chasin (2007, p. 1). From this comment by Chasin (2007, p. 1) it can be speculated that besides the attenuation abilities of the filter used in the Noise Clipper®, the material of construction (acrylic) causes the attenuation of the high frequencies to be more consistent and effective than that of lower frequencies.

Neitzel et al. (2006, p.10) studied the variability of real-world HP attenuation measurements making use of a REAT measurement system, referred to as the FitCheck method and the MIRE measurement system, referred to as the FlashTest method. Measurements were made on foam ear plugs and a CHPD. Both the measuring systems produced negative

attenuation results implying amplification of sound at certain frequencies. The mean frequency-specific measured attenuation never exceeded the labeled attenuation of the CHPD. This is consistent with the results found in the present study where frequencies below 250 Hz was amplified and mean attenuations values were below the REAT derived attenuation values.
Shanks and Patel (2009, p. 24) evaluated the attenuation performance of five different CHPDs using the REAT method of attenuation measurement. Some of the CHPDs was vented and some were solid while one CHPD had to be 'custom made' by the subject. One of the CHPDs presented with flat attenuation characteristics while the remaining four presented with a gradual increase in the levels of protection with increasing frequency. The attenuation characteristics of the four CHPDs are found to similar of that of the Noise Clipper® CHPD. A further similarity is that for all the custom-moulded earplugs tested, the average measured attenuation values were less than the manufacturer's values in all frequency bands and is consistent with the findings of this study.

Attenuation consistency had to be evaluated over the three days of measurement to determine attenuation stability. The results are discussed in the following section.

5.1.2.2 The influence of time of measurement on the attenuation level

Though statistically significant correlations were found between all measurements over the three days, the strength of the relationship was not the same for all three days. From these results it became clear that the attenuation of the Noise Clipper® as measured over three days were unstable. This instability was further illustrated by the absolute average differences in attenuation levels across frequencies between day two and day three that were calculated as 3.24 dB(A) while the average difference calculated between day one and day two were 5.54 dB(A). As stated before, the ideal HPD should attenuate in a linear way with the same amount over consecutive days. In this study it was found that not only did the noise levels fluctuate over the three days, but that a significant increase in attenuation over three days was found with the exception of the frequencies below 250 Hz. Large standard deviations were present for the frequencies below 1000 Hz and smaller standard deviations were found for the frequencies above 1000 Hz.

Nelisse et al. (2011, p. 1) established that, for most workers tested, considerable fluctuations over entire work shift periods were found in the attenuation data reported as a function of time . "Part of these fluctuations is attributed to variations in the low-frequency content in the noise (in particular for earmuffs) as well as poor insertion and/or fitting of earplugs" (Nelisse et al., 2011, p. 1). In Table 17 of the present study, the highest mean

attenuation of 18.35 dB(A) was found at 4000 Hz. In the present study the mid to high frequency component (1000 Hz to 5000 Hz), was measured below the occupational exposure limit of 85 dB(A) for all the days of measurements. The mean attenuation levels measured per day and presented in Figure 18 indicated that adequate attenuation was measured over all three days; day three yielded the highest attenuation results. A possible explanation for the gradual improvement in attenuation over the three days is that of the insertion of the Noise Clipper® by the subject. It can be speculated that the subjects were more aware of the research process, therefore taking more care with the insertion of the Noise Clipper®, which could have led to improved attenuation. This phenomenon was also found in the studies of Franks et al. (2003, p. 504) and was termed the "learning effect".

As with the studies of Perala (2006, p. 129), a significant decrease in noise reduction was observed at 8000 Hz for all three days. Perala (2006, p. 129) made the following comment on these findings: "While these results may be related to acoustic impedance or a standing wave created by resonance effects near the tympanum, it is unclear whether distance from the tympanum, probe tube characteristics, or some other factor was responsible". He suggested that further research is needed to determine the exact cause and nature of this occurrence. A possible cause for the fluctuation in attenuation measurements is described by McKinley and Bjorn, (2004, p. 6). They attributed fluctuations in attenuation measurements to the insertion of the HPD by the worker. The fit of such a device may differ from person to person. Leakage as well as trapped air at the distal part of the device (in the meatus) may occur, causing passive attenuation to vary (Steeneken, 2006, p. 11). The research of Franks et al. (2003, p. 506) found that the experimenter-fit method yielded the greatest attenuation and the smallest standard deviations, confirming the effect that a good fit of a HPD may have on its attenuation abilities.

McKinley and Bjorn (2004, p. 7) found that the size of the acoustic leak between the HPD (earmuff) and the head had a dramatic effect on passive HPD performance. They conducted research on CHPDs and measured the effect of the customizing process on overall attenuation. The customizing of the device lead to improved leak-tightness, causing better attenuation results and they concluded that proper fitment of such a device had a detrimental effect on attenuation abilities. This is also evident in the studies of Lancaster and Casali (2004, p. 19) and Randolph and Kissell (2009, p. 3). The latter researchers investigated the effect of insertion lubrication on attenuation of foam earplugs and established that lubricated earplugs obtained a 5 dB and more improvement in attenuation than unlubricated ones. Their study was conducted because a need for proper fitment and seal-tightness was identified as a prerequisite for optimal attenuation (Randolph & Kissell, 2009, p. 1).

One of the most important aspects of a HPD is the amount of attenuation it provides. The attenuation characteristics must take into account the relationship between over- and under-attenuation. Bockstael, Botteldooren and Vinck (2008, p. 2258) postulated that the MIRE technique and the use of CHPDs were becoming more sophisticated and widespread. For this reason, knowledge of the underlying acoustical mechanisms involved when wearing HPDs is essential, especially with regard to some variations found in the SPLs measured by the MIRE microphone at the inner bore of an otoplastic and at the level of the tympanum. They expected an apparent difference between these two points at different frequencies and referred to it as the "transfer function". Of particular interest are the variations of the transfer function among humans. Despite the fact that further research on this topic needs to be done, they suggest that the transfer function between the sound pressure of the MIRE measurement microphone and at the tympanum can be predicted via "Finite Difference Time Domain" simulations with an individualized set of geometrical parameters. By making use of this protocol, the MIRE measurement corrected with these simulated transfer functions "can provide for each individual an accurate estimation of the effective exposure level when wearing these earplugs" (Bockstael et al., 2008, p. 2261). Although correcting factors (TFOs) was used for the F-MIRE measurement protocol in the present study the results may be altered should the corrected simulated transfer functions described by Bockstael et al. (2008, p. 2261) be used, the reason being that TFO values calculated by these authors might be more precise than the values used in the present study.

5.1.2.3 Attenuation characteristics of Noise Clipper® evaluated by F-MIRE versus REAT

The results obtained in this study are consistent with what is found in the literature where real world attenuation (MIRE) is found to be less than REAT attenuation measurements. The frequency specific F-MIRE attenuation results found in this study were compared to the REAT results as supplied by the manufacturer of the Noise Clipper® (Figure 21). In this comparison (Table 11) it is clear that on average the F-MIRE method predicts significantly less attenuation (16.5 dB(A)) than the REAT method. The smallest difference was 7.7 dB(A) for 1000 Hz and the biggest difference was 24.5 dB(A) at 8000 Hz (Table 11). Although the attenuation values differed between the two test protocols, the attenuation pattern was found to be similar for both methods where progressive attenuation was found from 500 Hz to 4000 Hz (Figure 21). The results of the Pearson–*r* correlation coefficient (Welkowitz, et al., 1998, p. 175) indicated that although both the attenuation protocols produced related results, they were not exactly the same. The Noise Clipper® devices used in the workshops of the Impala Platinum mine were fitted with

a 110 dB filter (Pretorius personal interview, 2009). The Noise Clipper® was fitted with a totally sealed filter setting for the REAT test measurements conducted by the SABS (Pretorius, personal interview, 2009). The result of these measurements (supplied by the manufacturer) was used for the comparison of attenuation ability between the F-MIRE and REAT results. Large attenuation differences were found between the F-MIRE and REAT results. The differences may be ascribed to the two evaluations not having the same filter settings (110 dB for the F-MIRE and 120 dB for the REAT). The implication is that the different test methods did not represent the true attenuation ability of the Noise Clipper®, which may lead to more workers developing noise induced damage.

Measuring the attenuation performance of HPDs in the field setting is an important but technically challenging task. It is important to measure the performance of HPDs when they are fitted by users in the workplace and to correlate the field attenuation with laboratory attenuation (North American Treaty Organization, 2010, p.1).

The F-MIRE attenuation protocol is a relatively new protocol compared to the REAT test protocol which is often referred to as the "golden standard" (Berger, 2007, p. 1). Throughout literature it is found that laboratory derived REAT attenuation results are overestimated when compared to real world attenuation. Even though this protocol is regarded to be the "golden standard" of attenuation measurement, real-world attenuation measurements are almost always found to be much lower than the derived laboratory controlled REAT attenuation results (Randolph & Kissell, 2009, p. 1). Berger et al. (1996, p. 368) compared the laboratory test results of HPDs to 22 real-world studies and found overestimations of attenuation of between 140% and 2000%. Several studies have shown that the actual effectiveness of the devices are most often much lower than the results obtained during real world evaluations (Behar, 2007, p. 2; Berger, 2007, p. 1; Franks, et al., 2003, p. 502; Nelisse, et al., 2007, p. 18; Niquette, 2007, p. 4 and Vinck, 2007, p. 15;). The differences widely found between real world and manufacturers' data are said to be essentially due to the fit of the HPD and, specifically for earplugs, to the method of insertion and the acoustic seal (Arezes & Miguel, 2003, p. 1). The mining industry in South Africa relies on the attenuation results obtained through REAT measurements (Schophaus, personal interview, 2009).

5.1.3 Assessment of the effectiveness of the Noise Clipper®

The effectiveness of the Noise Clipper® was evaluated by using the attenuation data obtained from the F-MIRE test and the REAT assumed protection value supplied by the manufacturer. These results were compared against the South African legal limit of 85 dB(A) as

described in SANS 10083: 2004.

5.1.3.1 Effectiveness compared to South African legal criteria

The first comparison was made between the F- MIRE results measured in the workshop of Impala Platinum mine (Rustenburg division) and the South African legal limit of 85 dB(A) (SANS 10083:2004).

5.1.3.1.1 F-MIRE protocol

As described previously, the residual noise level was calculated as the difference between the mean ambient noise levels at a specific centre frequency minus the mean attenuation level in dB at the same centre frequency that was obtained using the F-MIRE test protocol. By using the F-MIRE results and comparing them to the South African legal limit of 85 dB(A) (SANS 10083:2004) it is found that 88% of the measurements presented with attenuation levels below 85 dB(A) (Table 9). It has been estimated that between 68 and 80 per cent of mine workers in South Africa are exposed to a time weighted average (TWA) of 85 dB(A) or greater, indicating a significant risk of hearing damage (Franz, 2001, p. 195).

5.1.3.1.2 REAT protocol

REAT measurements were not conducted in this study. The assumed protection value used for the comparison to the South African legal limit of 85 dB(A) was supplied by the manufacturer of the Noise Clipper® (Pretorius, personal interview, 2009). Using the same criteria as with the F-MIRE attenuation results, the degree of effective attenuation was expressed in percentiles (Table 10). From this data it is clear that, in contrast to the F-MIRE results, all workers will be sufficiently protected against NIHL.

As described in previous sections of this thesis, the REAT attenuation protocol is highly criticized, partly because it is a subjective laboratory controlled measurement trying to predict real world attenuation performance of a HPD (Burks & Michael, 2003, p. 3). Voix and Hager (2009, p. 1) cautioned that laboratory evaluations (REAT) have not been proved to predict actual performance of HPDs in real world situations while Canetto (2009, p. 145) described field conditions in industry to be very different from those of laboratories at which tests are conducted.

This is significant in that the South African legal limit for HPD attenuation performance is based on REAT derived values. REAT attenuation values were found to overestimate the attenuation abilities of HPDs (Behar, 2007, p. 2; Berger, 2007, p. 1; Franks et al., 2003, p. 502; Nelisse et al., 2007, p. 18; Niquette, 2007, p.4 and Vinck, 2007, p. 15). A further concern regarding the use of over estimated REAT results is that actual protection and attenuation during

real world situations may be much lower than the REAT derived values (Berger, 2000, p. 379; Burks & Michael, 2003, p. 724; Neitzel et al., 2006, p. 2). More than R448-million in settlements were paid to 43 818 mineworkers in South Africa between 1998 and 2003 as a result of NIHL (Begley, 2004, p. 2). With the incidence of NIHL increasing worldwide (Begley, 2004, p. 2) it can be speculated that the assumed protection value of HPDs are overestimating attenuation effectiveness of the devices causing workers to be under-protected against noise damage.

A further aspect regarding attenuation effectiveness of HPDs that is mostly overlooked in literature is the findings of Mills and Going (1982, p. 121) concerning the BT for TTS. In order to answer the research question in terms of the attenuation effectiveness of the Noise Clipper® attenuation characteristics it was compared to the criteria of BT for TTS described by Mills and Going (1982, p. 121). This matter is discussed in the following section.

5.1.3.2 Effectiveness of the attenuation of the Noise Clipper® compared to the BT for TTS

From the data in Figure 22 it is clear that the median measurements suggested adequate protection below the critical levels (biological threshold) per centre frequency. The critical levels per centre frequency as provided by Mills and Going (1982, p. 121) are 74 dB SPL for 4000 Hz, 78 dB SPL for 2000 Hz, 82 dB SPL for 1000 Hz and 500 Hz (Mills & Going, 1982, p. 119). In Table 16 a more detailed analysis of the measurements is presented in percentiles. The results demonstrate that, across frequencies, 87% of the measurements indicated adequate protection, but 13% indicated thresholds to be at risk for developing NIHL, exceeding the BT for TTS between 1 and 14 dB. The significance of these findings lies in the fact that should the Noise Clipper® attenuate noise below the South African legal limit of 85 dB(A) (SANS 10083:2004) but not below the BTs described by Mills and Going (1982, p. 121) hearing loss may still develop over time. Not recognizing the validity of the Mills and Going study (1982, p. 121), may be one of the reasons that the incidence of NIHL is still high, questioning the validity of the ‘safe’ limit of 85 dB(A). Besides the research of Mills and Going (1982, p. 121), no other studies could be found regarding BT for TTS.

This study aimed not only to analyze the acoustical attenuation efficacy of the Noise Clipper® but also to determine the perceptions of the subjects concerning the comfort afforded by this HPD. The findings of the comfort evaluation are described in the following section.

5.2 The perception of the subjects regarding the comfort levels afforded by the Noise Clipper®

Subjects' perceptions of the level of individual items that contribute to the measure of comfort-discomfort are indicated in Table 14. Any scale achieving a high correlation with the central scale can influence the subjects' perception of HPD comfort (Arezes & Miguel, 2002, p. 536). From these results, it can be concluded that 75% of the subjects indicated that the Noise Clipper® was perceived as being comfortable. In the present study the majority of the respondents found the Noise Clipper® uncomplicated and easy to fit. This is significant since one of the greatest concerns of researchers is the fitment of the HPD in the ear canal by the subjects. Park and Casali (1999, p. 161) remarked that the comfort of some HPDs was influenced by the fitting procedure and the eventual attenuation abilities. Seventy five percent of the subjects found the Noise Clipper® to be painless, that it exerted no pressure, that it was hard, smooth, had a good fit, was closed, tolerable, did not induce a feeling of isolation, was simple to fit, light and tight. Because the comfort rating scale was used in other studies that evaluated comfort levels of different types of HPDs, for example, foam earplugs and ear muffs, some of the variables did not apply to the Noise Clipper®. For instance, it was expected that the respondents would report the Noise Clipper® to be hard since it is constructed of acrylic material. The variable cold/hot pertains to earmuffs that is often reported to be hot and uncomfortable, specifically in the mining environment (Schophaus, personal interview, 2009). In the initial training on how to fit the Noise Clipper® guidance was provided to the workers on how to insert and maintain the HPD. The success of the induction given by the Noise Clipper® Company's team during the fitment process of the HPDs is reflected in some of the positive responses in the rating scale. This statement is justified, since the respondents found the insertion into the ear canal to be simple and the fitment to be good. Seventy five percent of the subjects indicated that they did not experience isolation when using the Noise Clipper®, therefore (although not formally evaluated in this study), it can be speculated that the subjects did not experience over-protection when using the Noise Clipper®. Davis (2008, p. 85) outlined the existing research on HPD comfort and discussed some recent laboratory and field studies relating to comfort issues regarding HPDs. It was found that hearing protector comfort may be reliably and validly quantified on psychophysical scales and that workers could consistently rate hearing protector comfort on multiple psychological scales. In this study only the subjective evaluation of comfort was evaluated, although other ergonomic features do exist as described above.

Park and Casali (1991, p. 172) evaluated the comfort levels of three different types of HPDs, namely canal caps, foam plug and ear muffs. Although the foam plugs were recognized to be the most comfortable it was also found that the subjects did not insert the plugs deep enough into the ear canals, leading to leaks that affected the attenuation abilities. The same researchers studied the feasibility to devise a reliable short-term laboratory based test which can realistically estimate field HPD comfort. Their conclusion was that the field study comfort results did not validate those of the laboratory study and suggested that further research in this area should be done. Christian (2000, p. 75) evaluated the comfort levels of HPDs using the same bi-polar rating scale used in the present study. The focus of her study was to compare the comfort levels afforded by three different types of HPDs: an active noise reducter earmuff, a passive earmuff and a user-moulded foam earplug. No significant differences in comfort ratings could be found between the three HPDs. Neitzel et al. (2006, p. 1) evaluated comfort levels of different types of HPDs and found that the custom-moulded earplugs had higher overall acceptance among workers than conventional HPDs.

Shanks and Patel (2009, p. 23) studied a selection of CHPDs available in the United Kingdom. The study was carried out to examine their attenuation abilities and to identify influencing factors on protection, comfort and fit. Only three of the five devices evaluated were found to be comfortable. They concluded that comfort is compromised should inexperienced users mould earplugs. Because of this finding the researcher determined that intensive training on taking the impressions (Pretorius, personal interview, 2009) was provided to the Noise Clipper® personnel by an experienced audiologist.

A few different approaches to assessing HPD comfort have been proposed, but none have gained widespread acceptance (Byrne et al., 2011, p. 87). One such study is that of computer modeling for comfort prediction developed by Baker, Lee and Mayfield (2010, p. 2). They described the interaction between a HPD and the human ear as the primary deterrent for wearer discomfort. Their research led to the development of a computer program using three-dimensional scanning technologies to predict wearer comfort/discomfort. The results of their study showed that “discomfort is a function of contact pressure and area” (Baker et al., 2010, p. 2). They concluded that the initial modeling work demonstrated that predictions could successfully be made of comfort levels afforded by HPDs, although additional research should be done to include a wide range of HPDs.

Factors not evaluated in the present study that may have had an effect on the acceptability of wearing HPDs, are those of humidity, dust and perspiration that are so prominent in the mining industry. Arezes and Miguel (2003, p. 1) noted that additional key

parameters of performance, such as comfort levels, can lead to workers' dissatisfaction and, consequently, misuse of HPDs. This may alter the overall attenuation afforded by the HPD significantly. HPD comfort, during extended usage, is not specifically included in methods for testing HPD efficacy (Arezes & Miguel, 2003, p. 1). As described in previous sections of this study, wearing time will have an effect on the attenuation effectiveness of the Noise Clipper® and should therefore be included in the evaluation of comfort.

The remarks of Park and Casali (1999, p. 178) in the conclusion of their study on comfort levels validated the need for the present study in that no accepted consensus standards for HPD comfort evaluation exist (specifically of CHPDs). Although no consensus standard was developed in the present study the findings may lead to the development of such a standard.

Byrne et al. (2011, p. 87) are of the opinion that 90 % of industrial noise levels do not exceed 95 dB(A), and that most HPDs are capable of producing 10 dB of attenuation necessary to reduce the exposure to 85 dB(A) and below. This moves the focus of HPD selection away from attenuation ability to comfort for the consistent use during a full work shift *(*Byrne et al. 2011, p. 87).

Throughout literature, it is well known that under-attenuation of HPDs is of great concern because it may lead to irreversible cochlear damage. The negative effect of over-attenuation is often overlooked in the selection of HPDs. Conventional HPDs may have a negative influence on the hearing ability of users and have often been implicated in compromised auditory perception, degraded signal detection and reduced speech communication abilities. "The result is that it becomes hazardous for the wearers of these devices depending upon situational demands, or at the very least causes resistance to use by those that need hearing protection" (Casali & Robinson, 2003, p. 65).

5.3 The self-reported wearing time of the subjects using the Noise Clipper®

Seventy nine percent of the subjects indicated that they used the Noise Clipper® for a full eight hour work shift. As mentioned before, respondents have a strong tendency to exaggerate answers and to perceive researchers to be government agents with the power to punish or reward according to the substance of their answers (The Survey System's Tutorial, 2001, p. 16). Twenty percent of the subjects indicated that they used the Noise Clipper® for six hours or less during an eight hour work shift. As demonstrated in Figure 5, the attenuation effectiveness of Noise Clipper® is reduced when not used for a full eight hour work shift as described in the studies of Arezes and Miguel, (2002, p. 533); Davis and Sieber (1998, p. 721); and Vinck (2007, p. 19).

As with the studies of Lusk et al. (1999, p. 493); Arezes and Miguel (2002, p. 533); Park and Casali (1991, p. 177) wearing time evaluations differed from the present study in that different types of HPDs were evaluated and compared. Lusk et al. (1999, p. 493) tested the effectiveness of a theory-based intervention where workers received training concerning the use, insertion and maintenance of a HPD, as well as an explanation of the necessity of using HPDs. This was done to increase the use of HPDs and it was found that this intervention resulted in a significant increase in the use of HPDs. Arezes and Miguel (2002, p. 535) found a statistically significant correlation between comfort and wearing time and remarked that HPDs with a high comfort index had high wearing time values and vice versa. Morata et al. (2001, p. 26) used a four-point scale ranging from "never" to "all the time" to determine wearing time of HPDs. They found the use of HPDs to be very low, since only 16 out of the 124 workers who were evaluated indicated that they used HPDs all the time when exposed to noise. They further investigated the reasons for not wearing HPDs and found that discomfort and interference with speech and warning signals were the most prominent reasons for not using the devices consistently (Morata et al. 2001. p. 34). The Noise Clipper® manufacturer can therefore be advised to investigate the problem of speech and warning signal interference. A recent study on self-reported wearing time, conducted by Griffin et al. (2009, p. 646) found that workers in steady state noise environments reported more accurately than workers in variable noise environments. This observation demonstrates the potential importance of noise exposure variability as a factor that may influence self-reported wearing time accuracy.

5.4 Summary

In this chapter the results and findings of this study were discussed. The fluctuations in noise levels measured over three days were consistent with the finding of Durkt (1998, p. 11). In the evaluation of the noise spectrum it was found that the frequencies below 1000 Hz were relatively unstable and that frequencies above 1000 Hz had elevated noise levels as measured over three consecutive days. It was further found that these elevated noise levels were constantly present at high intensities. The results of a post-hoc analysis for both the Tukey HSD and Scheffé methods (Roberts & LLardi, 2003, p. 104) revealed that frequencies above 1000 Hz had significantly higher noise levels than frequencies below 1000 Hz. The spectral characteristics of the attenuation pattern showed that, on average, attenuation was observed for all centre frequencies above 250 Hz, whilst amplification was present at frequencies below 250 Hz. The highest mean attenuation of 18.35 dB was measured at 4000 Hz. The F-MIRE and REAT attenuation results were compared and it was found that on average that the F-MIRE

method predicts significantly (16.5 dB) less attenuation than the REAT method across all frequencies. When the F-MIRE attenuation results were compared to the South African legal limit of 85 dB(A) (SANS 10083:2004), 88% of the measurements indicated that attenuation levels where below the action level of 85 dB (A) when using the Noise Clipper®. Comparing the same F-MIRE results to the BT for TTS it was found that 10.5% of the measurements indicated insufficient protection for the low frequencies; 16.0 % for the middle frequencies; and 25 % for the frequencies above 2000 Hz.

According to the results of the bi-polar comfort rating scale 75 % of the subjects found the Noise Clipper® to be comfortable and 79 % of the subjects indicated that they used the device for a full eight-hour work shift.

Chapter 6

Conclusions, limitations and suggestions

6.1 Conclusions

In this chapter the main conclusions derived from the research, as well as the limitations of the study are discussed. Finally, suggestions for future research are provided. Even though the overall ambient noise levels were below the South African legal limit of 85 dB(A), the maximum measurements for all the centre frequencies were above 85 dB(A) and ranged between 88 dB(A) and 95 dB(A) (Table 3).

The noise levels and noise spectrum measured in this study signified that the mine where the measurements were made needs to maintain its current hearing conservation program and that until noise control is successfully implemented HPDs will have to be used. It was hypothesized that, since the Noise Clipper® was custom made, individually fitted and that seal tightness was verified, predictions regarding performance could be made. This hypothesis proved to be wrong in that significant inter-day fluctuations were found. The attenuation data revealed that only 88 % of the measurements where below the action level of 85 dB (A) suggesting that subjects were protected against- NIHL should the F-MIRE test results be used to describe the attenuation ability of the Noise Clipper®. This finding is significant in that the REAT data suggest that all subjects (100 %) were sufficiently protected. The danger of using REAT derived measurements lays in the fact that it over estimates the protection afforded to most occupationally noise exposed workers.

The results of this study have shown that the protection provided by the Noise Clipper® varies, depending on the type of noise spectrum present and possibly on poor fitment of the HPD by the subjects. However it was considered to be effective for the majority of measurements made (88%) based on the statistical outcomes and the inclusion criteria for the current study. Improved attenuation thresholds were found over the three days, with day three presenting the highest values (Figure 18). Descriptive statistics were applied for the evaluation of attenuation thresholds compared to the BT for TTS. The initial concern that this concept (BT for TTS) is ignored in HCPs is negated by the fact that 83 % of the measurements (using the Noise Clipper® CHPD) revealed thresholds below the BTs for TTS. Seventy five percent of the subjects indicated that the Noise Clipper® was comfortable to wear, while 79 % reported that they used it for a full eight hour work shift.

The value of this study lies in the fact that most of the subjects perceived the Noise Clipper® to be comfortable to wear for a full eight hour work shift. The F-MIRE attenuation protocol proved

to provide more conservative estimates of HPD attenuation performance than the REAT results. Based on statistic outcomes and the inclusion criteria for the current study the assumption is made that should proper training be given to workers the overall attenuation results can be higher than measured in this study. By simplifying the F-MIRE test protocol and measurement equipment "repeated tests on each subject will result in more reliable estimates of an individual worker's attenuation, and increase confidence that NIHL will be prevented" (Neitzel et al., 2006,p.12).

6.2 Limitations of the study

The greatest limitation of this study is that no analysis or linkage of the F-MIRE attenuation results was made to n=40 ears or n=20 workers. A further limitation of this study is that the participants were not reflective of the mining workforce in South Africa as the experimental group was too small. Only low levels of noise exposures were measured and the attenuation response of the Noise Clipper® CHPD in high noise levels is unknown. Real-world attenuation results measured in this study can be misleading in that only seal-tight units were selected for the study. An additional major limitation is that instantaneous noise measurements were made for both ambient noise and attenuation effectiveness. Instantaneous measurements are sufficient in workplaces where constant noise levels are present but in this study variable noise levels were found in the Impala Platinum mine workshop in Rustenburg. The workers' average exposure to noise over an eight hour work shift was not measured. It is therefore not known what the nature of impulse noise was in the workshop and how the Noise Clipper® CHPD would respond in the attenuation of such noise.

No laboratory controlled Noise Clipper® CHPD attenuation results for the IE-33 analyses were available to compare the outcome of real world measurements against. For this reason reliable estimates of the stability of the measuring instrument in real world situations could not be made with great certainty.

To speed up the F-MIRE measurements the researcher could have used an assistant, specifically for the venting of the otoplastics for microphone insertion.

The scale selection of the bi-polar comfort rating evaluation leads to another limitation. The rating scale used in the present study was not adapted from the original scales used by Arezes and Miguel (2002, p. 536) and Park and Casali (1999, p. 161) for the description of the Noise Clipper®. The scales used in the research of the mentioned authors were selected to evaluate more than one type of HPD, that is, ear plugs, CHPDs and ear muffs. A further limitation was found in the scale selection of the bi-polar comfort rating evaluation. The rating

scale used in the present study was not adapted from the original scales used by Arezes and Miguel (2002, p. 536) and Park and Casali (1999, p. 161) to describe the Noise Clipper® HPD. The limitation pertaining to this study is that some of the scales were not applicable to the Noise Clipper® CHPD, causing some confusion in subjects and affecting the statistical outcome of the comfort evaluation.

Another limitation was that the researcher had to rely on the honesty of the subjects concerning the wearing time of the Noise Clipper® and not on personal observations.

A final limitation is that only one (enforced) HPD was evaluated. With the workers not being exposed to other types of HPDs their opinion on comfort perception could have been altered significantly.

6.3 Suggestions for further research

- As with the studies of Lusk et al. (1999, p. 493) a theory-based intervention should be conducted and tested to increase the effectiveness of use of the Noise Clipper® with specific focus on the correct fitment procedure. It would therefore be recommended that repeated attenuation measurements be made to ensure that the individuals' measured attenuation is stable across HPD refitting (Neitzel et al., 2006, p. 12).
- The F-MIRE protocol has the potential for measuring individualized attenuation values instead of relying on single number of estimates similar to the NRR placed on HPDs (Franks et al. 2003, p. 508). Research should therefore be directed to simplify the F-MIRE protocol so that multiple tests may be performed per subject.
- Although, for the majority of subjects in this study the F-MIRE method provided a reliable measure of the performance of the Noise Clipper®, it could be used as a basis for a standard, although it is not an accepted standard in South Africa. In order to make this method an approved testing standard, a procedure for the F-MIRE testing technique needs to be formally drafted and proposed as a standard through the appropriate organizations or agencies.
- The F-MIRE test protocol should be performed on other HPDs to determine if the variances found in the present study are due to the HPD itself or to the test protocol.
- A larger sample size will be more representative of the attenuation characteristics of the Noise Clipper® and may result in data with a high level of internal validity regarding attenuation and protection from noise damage. Since production is of great concern in the mining industry, it is suggested that more than one mining group be approached, causing the productivity of one mine only to be less affected.

- The study could be repeated in other noise hazard environments and or other physical locations.
- A study can be conducted using a random group of subjects without the control of a seal tight test and length of wear time.
- The comfort rating scale should be adapted so that the perceptions and actual comfort needs of workers in the South African mining industry may be determined in the same manner as described by Yeh-Liang Hsu et al. (2004, p. 545). These researchers consulted senior workers that used HPDs consistently for long periods to determine which aspects of a HPD they would consider to be comfortable. They then compiled a comfort rating scale that comprised the features as described by the workers. In addition, a correlation should be made between comfort and wear-time.
- Suggestions made by Park and Casali (1999, p. 178) are that, besides attenuation measurements, a standard set of rating procedures ought to be developed to yield reliable comfort rating estimates for HPDs and that environmental stressors such as various temperatures and humidity conditions be added to comfort evaluations (Park & Casali, 1999, p. 166). Perhaps the most important feature of comfort measurement is the potential for relating comfort to specific engineering design parameters of HPDs. Comfort ratings may be able to assist designers to specify more comfortable design parameters according to pre-established criteria.
- Speech communication quality is an important issue for a user in work conditions. The noise level at the ear is one of the major variables that define the speech communication quality **(**Steeneken, 2006, p. 1). Auditory perception, including speech intelligibility and sound localization, known to be particularly relevant in the workplace, should be investigated (Steeneken, 2006, p. 1).
- Although the mine where the measurements were made maintains a high level of occupational health policies, the researcher would advise its management that further education, motivation, and training regarding the use of HPD and hearing conservation should be implemented, specifically to line managers. The ambient noise exposure levels measured in this study indicated that the facility needs to maintain its current hearing conservation programme and that use of HPDs will be necessary until effective noise control measures are implemented.
- A final recommendation would be to determine the long-term attenuation effectiveness of the Noise Clipper® by evaluating the audiometric results annually. This should

include not only pure tone audiometry but specifically the use of oto acoustic emission testing and monitoring.

6.4 Summary

In this chapter conclusions were made of the attenuation effectiveness of the Noise Clipper®, and the implementation of the device on a large scale. The limitations were discussed and suggestions made for further research.

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Appendix (A)

Noise Clipper Survey
Comfort Index Questionnaire

Painless								Painful
Uncomfortable								Comfortable
No uncomfortable pressure								Uncomfortable pressure
Intolerant								Tolerate
Tight								Loose
Heavy								Light
Soft								Hard
Cold								Hot
Smooth								Rough
Feeling of complete isolation								No feeling of complete isolation
Good fit								Poor fit
Complicated to fit								Simple to fit
Ear open								Ear blocked
Ear empty								Ear full

1	2	3	4	5	6	7

For how long do you use the Noise Clipper during a work shift?

8 hours…….6 hours……..4 hours……..2 hours……

Appendix (B) **Noise Clipper Survey**
Comfort Index Questionnaire : Setswana

Ga go botlhoko								Go botlhoko
Ga go manono bonobo								Go manonobonobo
Ga di gatelele ditsebe thata								Di gatelela ditsebe thata
O ka se itshokele								O ka itshokela
Di tsimpa								Di bolea
Di bokete								Di botlhofo
Di boleta								Di thata
Di tsididi								Di bollo
Di borethe								Di magotsane
O ikutla o le nosi								O ikutla o se nosi
Di go lekanetse sentle								Ga di go lekanele sentle
Di mafaratlha tlha								Di bonolo
O ikutlwa e kete ditsebe tsa gago di butswe								O ikutlwa e kete ditsebe tsa gago di tswetswe
O ikutlwa e kete ditsebe tsa gago ga di na sepe								O ikutlwa e kete ditsebe tsa gago di tletse

1	2	3	4	5	6	7

O dirisa di Noise Clipper® nako e kana kang ka shifti kwa mmerekong?

Diura tse 8…….tse 6…….. tse 4……..tse 2…… ?

Appendix (C)

Letter of consent Impala Platinum Magagement

28 November 2008

Mr James van Rensburg
Impala Platinum
Rustenburg

Dear Mr van Rensburg

Re: Research on the effectiveness of the Noise Clipper® custom-made hearing protection devices at Impala Platinum, Rustenburg.

As a registered student for the M Communication Pathology Degree at the University of Pretoria, it is a requirement to conduct a research project. The title of the project is **Hearing protection in mines: Evaluating the Noise Clipper® custom made hearing protection device.**

The sub-aims formulated for the research are:

- To evaluate the attenuation characteristics of the Noise Clipper® CHPD in the natural working environment of surface workers in areas with noise levels of 85 dB and above. Twenty workers will be needed on a voluntary basis for this evaluation. A monitoring device will be used for the measurement of the noise field and the attenuation properties of the Noise Clipper® CHPD. Three measurements will be made of each worker on three consecutive days. It is envisaged that the time needed for this evaluation will be in the order of thirty minutes per evaluation per worker.
- The second objective will be to evaluate features related to the comfort of the Noise Clipper®, by making use of a questionnaire that will be administered by the researcher. This will be done on a one- to- one basis with the worker. It is envisaged that the time needed for each worker will be in the order of four to five minutes. To give validity to the outcome two hundred and fifty workers will be needed to participate on a voluntary basis. This part of the study will take place over a one week period.

Workers who do not want to take part in the study will not be penalised. Participants

may withdraw at any stage of the study without negative consequences. Every effort will be made to uphold the high standard of ethics and confidentiality during the research project. The information obtained will remain confidential as no names or company numbers will be required. The results of the findings will be made available to the management of Impala Platinum mine and will be stored for fifteen years at the Department of Communication Pathology of the University of Pretoria.

I would be very grateful if you could confirm your consent to me to use the workers of the Impala Platinum Rustenburg division as participants of this study by signing this letter. The written consent of the workers will also be obtained prior to the gathering of data.

Should you require any further information, feel free to contact me (cell: 0832899166 or e-mail: jkock@noiseclipper.co.za).

Kind regards,

Mr JFW Kock: _____

Researcher

Dr. M Soer: _____

Supervisor /Study leader

Prof. B. Louw: _____

Head: Department of Communication Pathology

Letter of Consent

I _____ hereby give permission for this research project to be conducted.

Signed for Impala Platinum, Rustenburg: _____

Date: _____/ 2008

Appendix (D)

Letter requesting informed consent: Implats employee- F-MIRE measurement

18 May 2009

Dear Impala Platinum mine worker

Re: Research on the effectiveness of the Noise Clipper® custom made hearing protection device in the Impala Platinum mine Rustenburg division.

As a registered student for the M Communication Pathology Degree at the University of Pretoria, it is a requirement to conduct a research project. The title of the project is "Hearing Protection in Mines: Evaluating the Noise Clipper® custom made hearing protection device".

The purpose of this part of the study is to evaluate the attenuation properties of the Noise Clipper® custom made hearing protection device that will be connected to a small hand held computer. You will insert the Noise Clipper® as you usually do. This evaluation will not affect your normal movement or working conditions.

The computer will measure the noise in your work area as well as the protection afforded by the Noise Clipper®. After the measurement the microphone will be removed, the second canal sealed and your Noise Clipper® will be handed back to you. There will be no risks involved in this evaluation.

After the study, a description of the results will be available in the form of a research report. The information gathered will give us a clearer understanding of the attenuation properties of the Noise Clipper® CHPD. This information will be used to select filter settings that will suit your specific noise environment.

Your participation in the study will be voluntary and you can withdraw at any time without any negative consequences. No compensation will be given. Please note that the evaluation/measurement will be conducted in such a manner that all data/information obtained from the measurements will be treated confidentially as your name or personnel number will not be needed.

According to the University of Pretoria's policy the data obtained will be stored in the Department of Communication Pathology for a period of 15 years.

Consent clause

I have read all the above, had time to ask questions, received answers to areas or questions concerned and willingly give my consent to participate in the study . Upon signing this form I will receive a copy.

Date:……../2009

Signed:……..

Researchers name:…….

Researchers signature:…….

Date:…… /2009

Appendix (E)

Letter requesting informed consent: Implats employee- Comfort evaluation

18 May 2009

Dear Impala Platinum mine worker

Re: Research on the effectiveness of the Noise Clipper® custom made hearing protection device in the Impala Platinum mine Rustenburg division.

As a registered student for the M Communication Pathology Degree at the University of Pretoria, it is a requirement to conduct a research project. The title of the project is “Hearing Protection in Mines: Evaluating the Noise Clipper® custom made hearing protection device”.

The purpose of this part of the study is to evaluate the subjective comfort afforded by the Noise Clipper® CHPD by making use of a questionnaire. You will be in a one-to-one basis with the researcher that will ask you some questions regarding the comfort of the Noise Clipper® CHPD that you use. Your participation is voluntary and anonymous. The proposed questionnaire is available to scrutinize and have access to intended questions so that you can make an informed decision if you will participate or not. You have the right not to respond to any of the questions in the questionnaire should you elect to do so. After the study the results will be available. The indirect benefit of the study will be that you will be protected against industrial noise damage. Your participation in the study will be voluntary and no compensation will be paid.

Your responses to the questions asked by the researcher will be anonymous, there is thus no risk of disclosure of personal information.

According to the University of Pretoria’s policy the data obtained will be stored in the Department of Communication Pathology for a period of 15 years.

Consent clause

I have read all the above, had time to ask questions, received answers to areas or questions concerned and willingly give my consent to participate in the study . Upon signing this form I will receive a copy.

Date:……../2009

Signed:……..

Researchers name:…….

Researchers signature:…….

Date:…… /2009

Appendix (F)

Ethics Committee University of Pretoria G90

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UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA
Faculty of Humanities
Research Proposal and Ethics Committee

21 October 2008

Dear Dr Soer

Project:	**Hearing protection in mines: Evaluating the Noise Clipper® custom made hearing protection device**
Researcher:	**JFW Kock**
Supervisor:	**Dr ME Soer**
Department:	**Communication Pathology**
Reference number:	**76262155**

Thank you for your response to the Committee's letter of 8 September 2008.

I have pleasure in informing you that the Research Proposal and Ethics Committee formally **approved** the above study at an *ad hoc* meeting held on 20 October 2008. The approval is subject to the candidate abiding by the principles and parameters set out in his application and research proposal in the actual execution of the research.

The Committee requests you to convey this approval to Mr Kock.

We wish you success with the project.

Sincerely

Brenda Louw

Prof. Brenda Louw
Chair: Research Proposal and Ethics Committee
Faculty of Humanities
UNIVERSITY OF PRETORIA
e-mail: brenda.louw@up.ac.za

Research Proposal and Ethics Committee Members: Prof P Chiroro; Dr M-H Coetzee; Dr JEH Grobler; Prof KL Harris; Ms H Klopper; Prof E Krüger; Prof B Louw (Chair); Prof A Mlambo; Prof G Prinsloo; Mr C Puttergill; Prof H Stander; Prof E Taljard; Dr J van Dyk; Prof C Walton; Mr FG Wolmarans