TITLE:

PERSONAL NOISE EXPOSURE IN PLATINUM CONCENTRATOR OPERATIONS IN THE BUSHVELD COMPLEX OF SOUTH AFRICA

Willem Bernardus Deysel

A research report submitted to the Faculty of Health Sciences, University of the Witwatersrand, Johannesburg, in partial fulfilment of the requirements for the degree of Masters in Public Health: Occupational Hygiene

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ABSTRACT

Introduction

The quantification and interpretation of personal noise exposure levels in the platinum processing industry of South Africa is an important research topic. Very few studies have been done nationally and internationally on noise exposure in this industry, given the serious health effects of over exposure to noise and the large number of people employed in this industry, this study is important.

Objectives

The objectives of this study were to describe personal noise exposure measurements of permanent and long term contractor employees during 2012 to 2014 at five Platinum Concentrator operations; to compare the personal noise exposure levels of the different activity areas between the five Platinum Concentrator operations; and to compare the personal noise exposure measurements of the Platinum Concentrator operations to national and international exposure limits.

Methods

This study was a cross-sectional secondary data analysis of personal noise exposure levels measured as part of routine Occupational Hygiene sampling programme during the period of 2012 to 2014 and was done in five platinum concentrator operations situated in the Bushveld Complex of South Africa. A total of 720 samples were extracted from an electronic database and descriptive statistics were applied to analyse the data.

Results

This study found that the Processor Grade 2 occupation within platinum concentrator no.3 had the highest personal noise exposure (104.7dBA) with a median personal noise exposure of 87.35dBA and a geometric mean personal noise exposure of 87.4dBA. Sixty seven percent of the personal noise measurements within the five Concentrator Operations exceeded the South African Occupational Exposure Limit of 85dBA and 19.71% of the personal noise measurement results exceeded the OSHA Exposure Limit of 90dBA.

Conclusion

This study indicated that over exposure to noise in the platinum processing industry can occur; therefore further research on this topic and in this industry is warranted.

DECLARATION

I, Willem Deysel declare that this research report is my own unaided work. It is submitted for the degree of Masters in Public Health: Occupational Hygiene at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any other degree or examination at any other University before.

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(Signature of candidate)

15th day of June 2017 in Johannesburg

Name of Primary Supervisor: Dr. Andrew Swanepoel

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Signature of Primary Supervisor

Date: 15 June 2017

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3. The Platinum Concentrator Operations studied, for allowing me to make use of the personal noise exposure data.
4. All other persons who assisted me and contributed to this project in one way or another.

ABBREVIATIONS

Abbreviation	Meaning
ANOVA	Analysis of Variance Between Groups
CIOM	Chief Inspector of Mines
COP	Code of Practice
DMR	Department of Minerals and Resources
HEG	Homogeneous Exposure Group
HPD	Hearing Protection Device
HSD	Honest Significant Difference
HPD_TAS_TOOL	Hearing Protection Device_Training, Awareness and Selection_Tool
GDP	Gross Domestic Product
IT	Information Technology
MHS Act	Mine Health and Safety Act
MOSH	Mining Occupational Safety and Health
MSHA	Mine Safety and Health Administration
MVS	Mine Ventilation Society
NIHL	Noise Induced Hearing Loss
NIOSH	National Institute for Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
OEL	Occupational Exposure Limit
PGM	Platinum Group Metal
PPE	Personal Protective Equipment
REL	Recommended Exposure Limit
SAIOH	Southern African Institute for Occupational Hygiene
SAMOHP	South African Mines Occupational Hygiene Programme
SANAS	South African National Accreditation System
SANS	South African National Standard
TWA	Time Weighted Average
USA	United States of America

DEFINITION OF TERMS

Term	Definition
$L_{Aeq, 8h}$	This is the A-weighted equivalent-continuous sound level, is also sometimes called the average sound level, and is based on a 3-dB energy exchange rate, which is normalised to an 8 hour working shift (1).

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CHAPTER 1 - INTRODUCTION

1.1. General Introduction

1.1.1. Background information

South Africa is a world leader in mining and is also famous for its abundance of mineral resources and accounts for a significant proportion of world mineral production and reserves (2). The country is the world's largest producer of platinum, and also one of the leading producers of gold, diamonds, base metals and coal (2). Mining also remains a major force in the South African economy and accounts for roughly one-third of the market capitalization of the Johannesburg Stock Exchange and during 2009 contributed about 1-million jobs (500 000 directly); a direct gross domestic product (GDP) contribution of 8.8%, with another 10% indirect GDP contribution; and over 50% of merchandise exports and continues to act as a magnet for foreign investment in the country (2, 3).

The mining industry presents a range of occupational health risks to its workforce, with exposure to noise identified as one of the most significant occupational health risks (4). The level of this risk led to the establishment and implementation of the Noise Milestones by the Mine Health and Safety Council, for the South African Mining Industry during 2005. These Milestones were set with the aim of achieving a reduction of noise levels in the South African Mining Industry and ultimately resulting in a reduction in the number of diagnosed NIHL cases within the South African Mining industry.

1.1.2. Problem Statement

Despite on-going efforts to improve the effectiveness of mine Hearing Conservation Programmes, noise exposure levels remain high, with the incidence of Noise Induced Hearing Loss remaining unacceptably high and have cost the South African mining industry in excess of R890 million in compensation claims alone from 1997 to 2007 (4). This cost does not include the impacts on productivity and the worker’s decline in their quality of life (4).

Figure 1 below shows the extent of the NIHL problem in the South African Mining Industry.

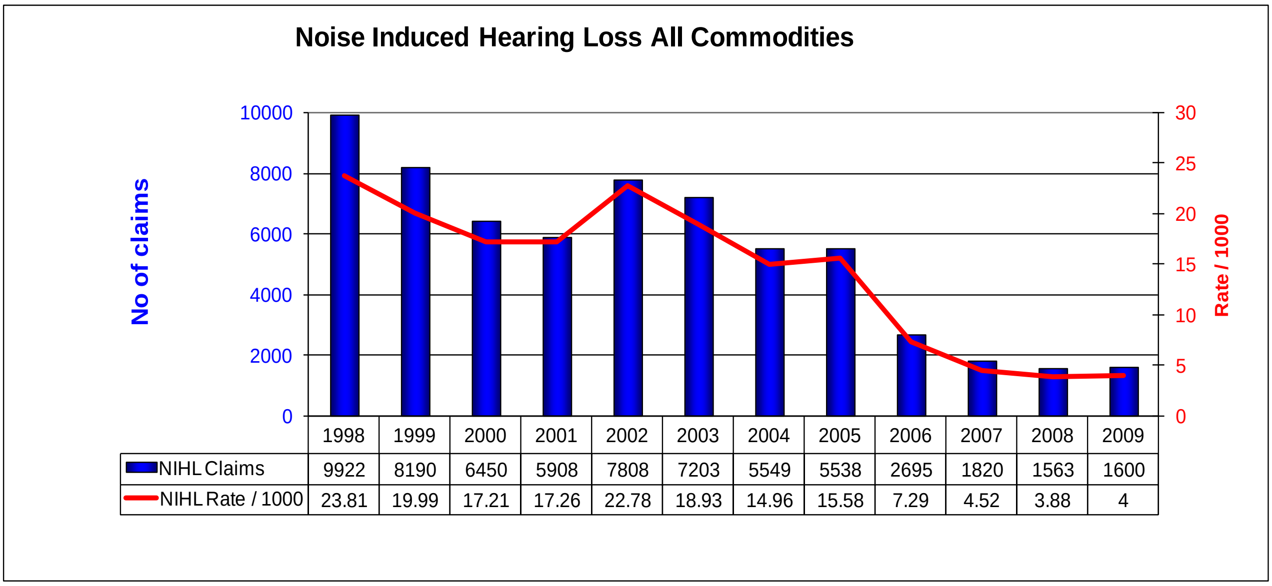

Figure 1: Number of reported NIHL cases and incidence rate of NIHL over a 12-year period in the South African Mining Industry (4).

As part of a study conducted during 1999, researchers calculated that the worldwide incidence of NIHL was approximately 1,628,000 cases per annum, at a rate of approximately 25 people per 100,000 per year (5). Occupational noise exposure in the working place is therefore a major concern for the health and safety of industrial workers, with NIHL remaining one of the most common occupational diseases worldwide (6). This is also true for the South African Mining industry, with the prevalence of NIHL remaining unacceptably high, despite legislated exposure limits, Code of Practices (COPs) and Hearing Conservation programmes (7).

The barriers to reducing NIHL in the South African Mining Industry include: gaps in knowledge of noise dose/source relationships; the unavailability of effective noise controls to reduce the noise levels in the working places to below hazardous levels; insufficient or inadequate worker education; and the empowerment of workers (4).

1.1.3. Concentrator operation overview

The objective at a Platinum concentrator is to concentrate the valuable materials in the mined ore into a workable mass, separating the valuable minerals for collection and discarding the unwanted minerals and materials. The Platinum ore from the shafts is trammed to the Concentrator Plant and is fed into the Plant on conveyor belts. Inside the Concentrator, the ore is crushed and screened in the Crushing section, to make the handling of the ore easier.

The crushing process is followed by the process of milling and classification stages. The Milling section is the last section in the Concentrator where ore reduction takes place. In this section, the ore is grinded (milled) into finer particles with an objective of liberating the valuable minerals from the unwanted minerals and also to prepare the pulp (slurry) for concentration process downstream. The milling process is followed by the flotation section, where the main separation of the valuable minerals takes place. Reagent chemicals and air are added in the flotation cells, which results in the Platinum Group Metals (PGM's) being attracted to the air bubbles which are skimmed off. The pulp is cycled through several stages of flotation cells, to ensure a maximum recovery and separation of PGM's from the tailings.

The final stage for the PGM's is thickening and filtration process, in which the water used during the milling and flotation processes are recovered for re-use. The dry concentrate, which is the final product of the Concentrator Operation, is then transported to the Smelter for further processing.

1.2. Literature Review

1.2.1. Characteristics of noise

Noise is defined as unwanted or undesired sound (1, 8, 9). Sounds are pressure waves in the air and have two key features, namely intensity (amplitude) and frequency. The sound waves are collected by the pinna of the outer ear, is then directed and enhanced into the middle ear through the ear canal. The ear canal shape and resonance properties amplify sounds between 2000 – 5000 Hz, which is an important feature for allowing soft sounds to be audible. The sound wave then impacts on the eardrum of the ear, which captures the sound wave vibrations, and passes them to the ossicular chain (also referred to as the middle ear bones). The function of the ossicular chain is to transfer the sound from the outer ear, through the middle ear and into the inner ear. Another important function of the ossicular chain is to amplify the sound, which allows humans to hear faint sounds. The ossicular chain then transfers the sound vibrations into the cochlea through the oval window in the cochlea and causes movement of the fluid within the cochlea. This results in the movement of the hair cells within the cochlea, which then converts this movement into an electrical type of signal. This signal is then sent to the brain by the auditory nerve, which is perceived and interpreted by the brain (1).

The frequency, expressed in Hertz (Hz), of the sound is defined as the number of pressure waves per second. The measurement unit of noise is the decibel (dB). This unit has no dimensions and is only a unit of comparison on a logarithmic scale which corresponds with a multiplication of intensity and is a function of the intensity and the frequency of the sound (1).

Figure 2 below is an illustration of a simple sound wave.

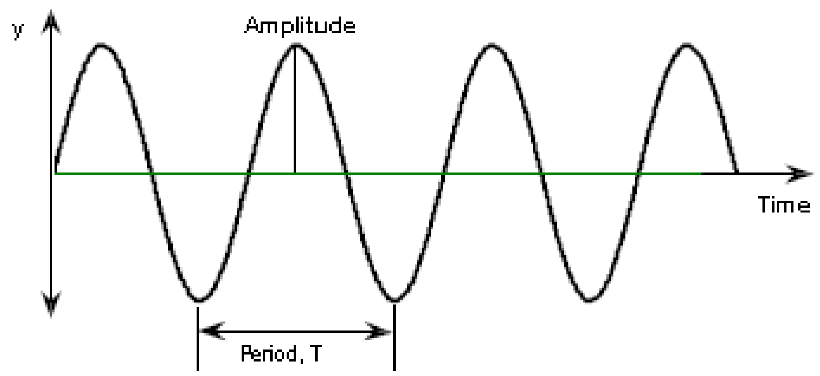

Figure 2: Simple sound wave.

The amplitude of a sound wave is the maximum pressure variation above and below atmospheric pressure and is directly related to the sound level. Sound waves with higher amplitudes are louder than sound waves with lower amplitudes (1).

The Period (T) of a sound wave is the time it takes to complete one full cycle and is proportional to the frequency(1).

The Wavelength (λ) of a sound wave is the length of one complete wave cycle and is measured in metres (m) (1).

The main factors that contribute to workers being exposed to high levels of noise in the mining industry include the use of heavy equipment; the inherently noisy aspect of ore winning processes; and the confined work environment (4). Significant reductions of the noise levels in the work place are rare due to the logarithmic nature of noise (10). For a three decibel reduction in the noise level, a reduction of the sound intensity level by two-fold is required (10).

1.2.2. <u>Measurement of Occupational noise exposure</u>

Personal occupational noise is measured with a noise dosimeter, which is a compact noise measurement instrument which integrates noise samples over a period and consists of the following main elements: a microphone, pre-amplifier, weighting network / filters, amplifier and a protective casing containing a display internal electronics and batteries.

The personal noise dosimeter measures the level of noise a worker is exposed to over a period of time, which is normally an 8-hour shift. This instrument is attached to the worker at the start of the working shift and is removed from the worker at the end of the shift. Personal noise dosimeters of a Type 2 accuracy is normally utilized for personal noise exposure measurements (11).

The full-shift personal noise measurement results which will be utilized in this study were conducted, in accordance with the South African National Standard (SANS) for the measurement and assessment of occupational noise for hearing conservation purposes, with reference number SANS 10083:2013 (12).

1.2.3. Health effects of over exposure to noise

Noise Induced Hearing Loss (NIHL) is an occupational disease, caused by exposure to high levels of noise in the working place and is one of the most common occupational illnesses in the South African Mining Industry (4). High levels of noise is generally defined as noise levels equal to or in excess of the OEL of 85dBA. The consequence of the disease is permanent and irreversible, with no effective medical treatment available to restore a person's hearing lost to noise exposure (5, 13). Exposure to noise in excess of an equivalent noise level of 85dBA at durations of more than 40 hours per week is considered to be associated with NIHL (6). NIHL is also much underestimated as an occupational disease in the working place, due to the slow onset and painless nature of the disease (6). Affected workers are unaware of the disease during the early stages of NIHL but will, over a long period, gradually notice loss in hearing, as a result of the permanent damage to the hair cells located within the cochlea of the inner ear after being over exposed for years (6).

1.2.4. Legislation in South Africa

1.2.4.1. Mine Health and Safety (MHS) Act

The Mine Health and Safety Act of South Africa (Act 29 of 1996) was signed off by the President of South Africa on 30 May 1996 and issued for implementation (14). The Department of Minerals and Resources (DMR) is responsible to enforce the implementation of the requirements of the Act and the monitoring of compliance.

1.2.4.2. COPs & SAMOHP

Chapter 2, Section 9(2) and 9(3) of the MHS Act requires employers in the South African Mining Sector to implement a COP on any matter which could affect the health or safety of persons who may be directly affected by the activities of a mine, if required by the Chief Inspector of Mines (CIOM) and must comply with the guidelines of the particular COP issued by the CIOM (14).

On 01 January 2002, the DMR issued a "South African Mines Occupational Hygiene Programme" (SAMOHP) Codebook, to guide employers in the setting up of the Occupational Hygiene Programmes required by the MHS Act (15).

On 01 March 2003, the CIOM issued a "Guideline for the Compilation of a Mandatory Code Of Practice for an Occupational Health Programme for Noise", with reference number: DME 16/3/2/4-A3 (16). In brief, this COP requires Mines to assess noisy activities/tasks/operations, implement personal noise exposure measurement programmes in the form of personal noise dosimetry, for the personal noise exposure measurement results to be linked to the medical surveillance conducted and the implementation of a Hearing Conservation Programme, for persons exposed to noise levels of equal to and above 82dBA (16).

1.2.5. Hearing Conservation & PPE

Hearing Conservation Programmes and Audiometry are mandatory in most countries, with the Occupational Safety and Health Administration (OSHA) in the United States of America (USA) requiring employers to maintain effective hearing conservation programmes when an employee's full-shift Time Weighted Average (TWA) noise exposure can reach or exceed 85dBA (decibels) (17, 18). A Hearing Conservation programme must include noise monitoring, training, hearing protection, and audiometric monitoring (19).

The topic of hearing conservation is the most difficult of all the possible health and safety topics applicable to the South African Mining Industry, one of the reasons being that there is no pain associated with hearing loss. Another reason is that people tend to enjoy activities which involve loud noise, such as concerts, sport events, hobbies (e.g. woodwork), etc. It is also not an easy task to convince people to wear hearing protection devices, which is often perceived as, uncomfortable Personal Protective Equipment (PPE), especially when the workforce cannot immediately feel or see the benefits of using the PPE (4).

1.2.6. Occupational Exposure Limit (OEL)

The OEL (also referred to as the Noise Rating Limit) for noise exposure, to which the operations classified under the MHS Act are required to comply to, is specified in Schedule 22.9(2)(a)(i)(1) of the MHS Act and is 85dB$L_{Aeq,8h}$ (14).

1.2.7. Findings and Conclusions of other Research Published

A literature search conducted revealed very little research conducted on the personal noise exposure of employees in processing operations, with limited published literature found on the personal noise exposure of employees in Platinum Concentrator Operations. This study is therefore an important study, which aims to add to the limited amount of knowledge published in research articles on personal noise exposure of employees in the processing environment of the platinum mining industry of South Africa.

The mining and processing of the earth's minerals requires a significant amount of high energy methods, which result in workers employed in the mining industry being exposed to high noise levels. Previous research reports quote that in 1981, an estimated 255 000 mine workers in the United States of America are exposed to noise levels of above 85dBA on a daily basis (20) and that these workers have a high risk of developing NIHL (21). A cross-sectional survey report on noise exposure in the mining industry, conducted by NIOSH, states that it was found that approximately 30 million workers were exposed to excessive noise levels in the United States of America during 1996 and that NIHL was the most common occupational disease at that time. The report continues with stating that if found that the problem of noise and NIHL was particularly severe in the Mining industry, with more than 90% of mine workers diagnosed with a hearing impairment by the age of 50 (22).

The picture for the South African mining industry is very similar to those reported above, with NIHL continuing to plague the South African mining industry, costing the mining industry millions of rand in compensation paid every year. During 2005, the Rand Mutual Assurance Company compensated 5 617 NIHL mine workers diagnosed with occupational NIHL at a total cost of R135.8 million, at an average of R24 177 per NIHL case (7). The parameter used most widely to characterize the level of risk to noise exposure is the noise level, which is measured in decibels, but it is very important that other important factors such as the duration of exposure, impulsivity, frequency and spectrum of the noise to which workers are exposed to daily be taken into account (9).

Published research reports on noise in mining operations confirmed that mining operations emit high noise levels, which would result in workers being over exposed to noise (21) and that it is believed that an increase in mechanisation resulted in an increase in noise levels present in mining operations, including mineral processing plants (8). Studies which focused on equipment or area noise measurements also found that large, high energy equipment installed in the mineral processing plants tended to emit higher noise levels, citing examples such as: large vibrating screens; rotating rock breakers / crushers; and mills (8), with noise levels of greater than 90dBA recorded at the vibrating screens and crushers (21). It is also suggested that these pieces of equipment could be defined as the most important sources of noise in the mineral processing plants (8). Noise measurements conducted for all areas within a mineral processing plant indicated that the noise levels ranged from 83dBA to 115dBA, with the noise level at most floors of the processing plant averaging in the upper 80dBA range and above, due to the nature of the construction of the buildings / floors, which tend to reverberate the sound waves rather than absorbing the sound waves (22).

A study conducted on the noise exposure and hearing loss among sand and gravel miners concluded that out of a total of 309 valid personal noise measurements conducted on workers, 213 (68.9%) samples had measurement results which were greater than the NIOSH Recommended Exposure Limit (REL) for an 8-hour work shift, with 128 (41.4%) of the samples returning results greater than the Mine Safety and Health Administration (MSHA) hearing conservation level (23).

1.3. Objectives

The objectives of this research study were as follow:

Objective 1: To describe the personal noise exposure measurements of the permanent and long term contractor employees recorded during the period of 2012 – 2014 at the five Platinum Concentrator operations and to compare the personal noise exposure measurements of the different activity areas between the five Platinum Concentrator operations.

Objective 2: To compare the personal noise exposure measurements of the Platinum Concentrator operations to national and international exposure limits.

CHAPTER 2 - METHODOLOGY

2.1. Study design

The study design of this research study is a cross-sectional secondary data analysis of the personal noise exposure results obtained as part of the routine Occupational Hygiene sampling programme during the period of 2012 to 2014.

2.2. Sampling

2.1.1. Sampling Strategies implemented at the Platinum Concentrator Operations

The five Platinum Concentrator Operations areas were classified into sampling areas and sub-classified into activity areas, as required by the SAMOHP Codebook, issued by the DMR.

2.1.2. Sampling areas

The main operational footprint areas (different processing Plants) of each of the five Platinum Concentrator Operations formed the sampling areas.

2.1.3. Activity areas

The main operational footprint areas of each of the five Platinum Concentrator Operations were sub-divided into the following activity areas, in accordance with the requirements of the SAMOHP Codebook, issued by the DMR. The applicable activity areas included the following: Crushing and Screening (DMR Activity area Code: 20); Milling and Pulverizing (DMR Activity area Code: 21); Separation processes (DMR Activity area Code: 23); Roving surface (DMR Activity area Code: 30).

2.1.4. Homogeneous Exposure Groups (HEGs)

The final classification of the employees was according to the intensity of the sound pressure level, according to the classification categories specified in the SAMOHP Codebook, issued by the DMR.

The DMR classification categories for personal noise exposure mentioned are explained in Table 1 below.

Table 1. Noise HEG Classification bands.

CLASSIFICATION BANDS FOR NOISE	
CATEGORY	**PERSONAL EXPOSURE LEVEL**
A	Exposures ≥ 105 dB $L_{Aeq,\ 8h}$
B	Exposures ≥ 85 ≤105 dB $L_{Aeq,\ 8h}$
C	Exposures ≥ 82 dB $L_{Aeq,\ 8h}$ and < 85 dB $L_{Aeq,\ 8h}$
D	Exposures < 82 dB $L_{Aeq,\ 8h}$

The sampling size and frequency of sampling of the exposed employees are explained in table 2 below.

Table 2. Frequency of noise HEG monitoring.

MINIMUM SAMPLING AND MINIMUM SAMPLING FREQUENCY	
CATEGORY	**MINIMUM FREQUENCY**
A	Sample 5% of employees within a HEG on an annual basis with a minimum of 5 samples per HEG, whichever is the greater.
B	
C	Sample 5% of employees within a HEG on a two yearly basis with a minimum of 5 samples per HEG, whichever is the greater.
D	No samples required.

2.1.5. Linking of employees and scheduling of sampling

The employees of each Concentrator Operation were linked to the HEGs at each of the Concentrator Operations. The electronic management system implemented at the five Platinum Concentrator Operations was also set-up to randomly select employees to be sampled, to ensure that the same employee would not be sampled repetitively over the sampling period.

2.3. Study setting

The data utilized for this study originate from five Platinum concentrator operations situated in the Bushveld Complex of South Africa.

The Figure below depicts the location of the Bushveld Complex in South Africa, where the Platinum Mines and Platinum Concentrator Operations are located.

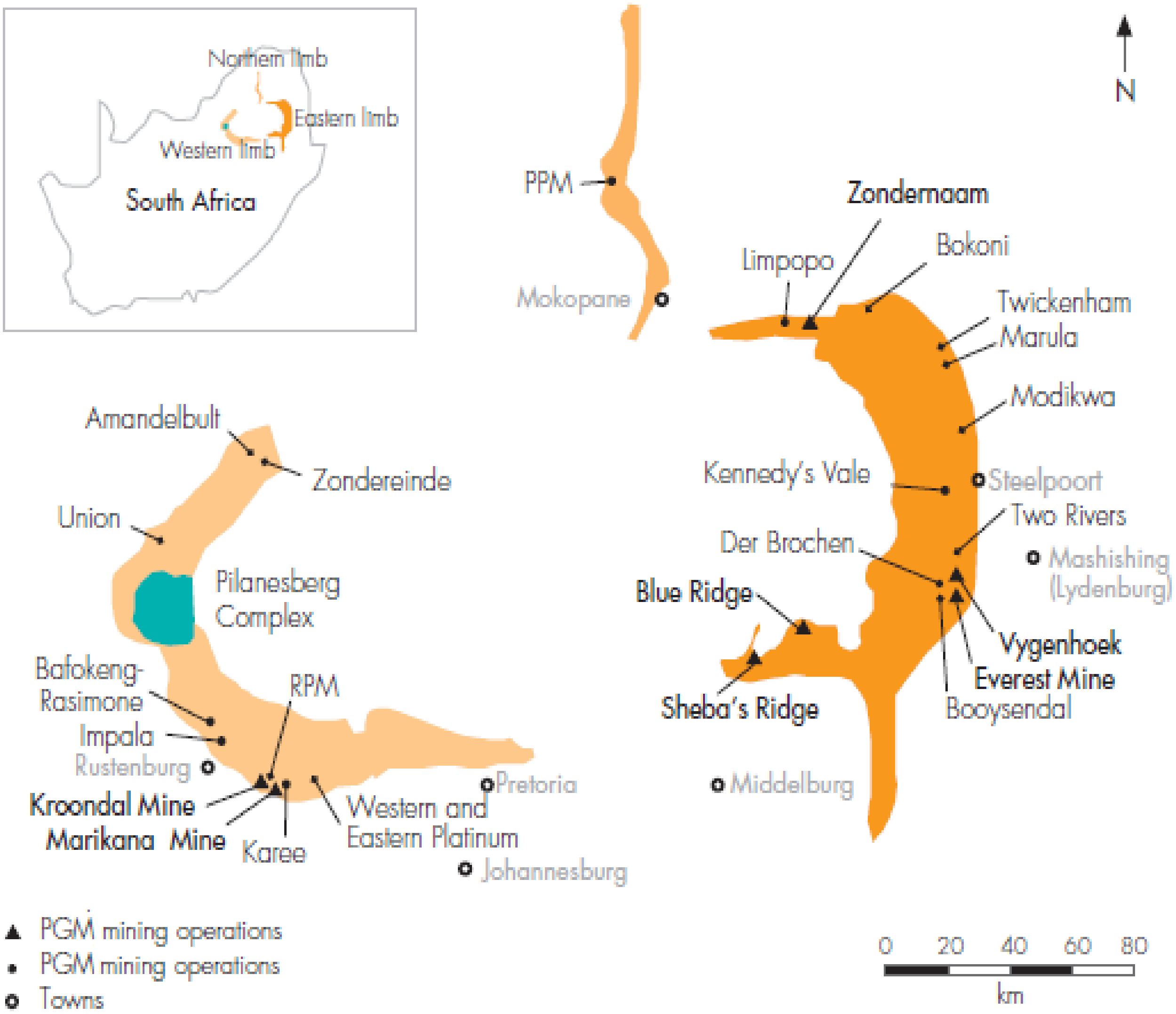

Figure 3: Location of the Bushveld Complex in South Africa(24).

In order to ensure anonymity, the names of the five Platinum Concentrator operations were changed to Platinum Concentrator operation 1; Platinum Concentrator operation 2; Platinum Concentrator operation 3; Platinum Concentrator operation 4 and Platinum Concentrator operation 5.

Table 3. Representation of the Activity Areas within the five concentrator operations.

Operation	Activity areas (Sections) within the Platinum Concentrator Operations where high noise levels are present			
Platinum Concentrator Operation no.1	One Crusher section	One Milling section	One Flotation section	Roving plant section
Platinum Concentrator Operation no.2	One Milling section	One Flotation section	Roving plant section	
Platinum Concentrator Operation no.3	Two Crusher sections	Two Milling sections	Two Flotation sections	Two Roving plant sections
Platinum Concentrator Operation no.4	Three Crusher sections	Three Milling sections	Three Flotation sections	Three Roving plant sections
Platinum Concentrator Operation no.5	Three Crusher sections	Three Milling sections	Three Flotation sections	Three Roving plant sections

The study population for the study includes the individual personal exposure measurement results of the permanent employees employed by the five Platinum Concentrator Operations, as well as all long term contractor employees performing work at the Platinum Concentrator operations. A total of 720 samples were exported in an Excel format from the electronic database, for the period of 2012 to 2014 and included the following variables: activity area; occupation and the noise measurement result in $L_{Aeq, 8h}$.

2.4. Data Management and Data Sources

The five Platinum concentrator operations made use of a web-based electronic management system, to group and link the study population to the established Homogeneous Exposure Groups. This system involves the setting up of activity areas, risk assessment, establishment of Homogeneous Exposure Groups, linking of exposed employees to the Homogeneous Exposure Groups, scheduling of samples and the capturing of sampling results. This management system also contained a database and data management tool, allowing only competent and authorised users to capture and access the personal noise measurement data.

2.5. Data analysis

The personal noise exposure measurement results were analysed with the application of a statistical software package (Stata v.12), with the descriptive statistical results obtained reported in a table format. The descriptive statistical data includes: the total number of samples; Minimum; Maximum; Median; Geometric Mean; Geometric Standard Deviation; Inter Quartile Range and the 90th Percentile.

The Personal noise exposure measurement results (sorted according to the activity areas mentioned and the occupations sampled) are presented in Box & Whisker plots, which illustrates the spread of the data analysed to the reader.

The Box and Whisker Plot allows the reader to, at a glance; obtain the range of the middle 50% of the data set (the box) and the total range (minimum and maximum) of the data set (the whiskers). The box also provides the range of the middle 50 per cent of the data set, normally called the inter-quartile range, which represents the range of the data set between 25% (the lower quartile) and 75% (the upper quartile) as well as the median value of the data set (25).

In order to effectively compare the personal noise measurement results between the different Platinum Concentrator Operations, the personal noise exposure measurements were sorted according to the activity areas mentioned in the COPs section for each Platinum Concentrator Operation, with hypothesis testing conducted in the form of the Analysis of Variance (ANOVA) test. The ANOVA test combines all the data into a single p-value, which was used to perform the hypothesis testing (23, 26).

In order to describe legal compliance in terms of personal noise exposure, the personal noise exposure measurement results were compared to the following national and international standards (23, 26): South African Occupational Exposure Limit (OEL) of 85dBA; and the Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) of 90dBA selected as the additional international standard which is different from the 85dBA standard.

2.6. Quality Control

The personal noise dosimeters were assembled, calibrated, attached and removed from workers by competent Occupational Hygiene Technologists registered with the Southern African Institute for Occupational Hygiene (SAIOH) or the Mine Ventilation Society (MVS). Sampling procedures for personal noise exposure monitoring, drafted in accordance with the requirements specified in SANS 10083:2013, were also implemented and adhered to at each of the five Concentrator Operations.

All the personal noise dosimeters utilized to perform the personal noise measurements analysed in this study were registered in the instrument register of the electronic management system, which ensures that the calibrations of these noise dosimeters are renewed on an annual basis, by notifying the responsible Occupational Hygiene Technologist a month in advance prior to the expiry of the annual calibration of each personal noise dosimeter. Only acoustical calibration institutions which are accredited by the South African National Accreditation System (SANAS) were utilized to perform the annual calibration renewal of the personal noise dosimeters.

The data analysed in this study was exported from the database of the web-based electronic management system and imported into the statistical software package utilized for the descriptive statistical analysis of the data.

2.7. Ethics

Permission to conduct the study was obtained from the Platinum Concentrator Operations appointed representative for each Platinum Concentrator Operation (appointed under section 4.1 of the Mine Health and Safety Act). An application for ethical clearance was submitted to the Medical Human Ethics Clearance Committee of the University of the Witwatersrand. The Medical Human Ethics Clearance Committee granted ethical clearance for this study and issued the researcher with Ethical Clearance Certificate no: M150640.

CHAPTER 3 - RESULTS

3.1. Descriptive Statistical Analysis

The statistical analysis of the data 8-hour Time Weighted Average personal noise exposure measurements conducted at the five Platinum Concentrator Operations were subjected to a descriptive statistical analysis.

The descriptive statistical data analysis of the 8-hour Time Weighted Average personal noise exposure measurement results, grouped according to Operation, revealed that the largest number of samples was conducted within Platinum Concentrator Operation No. 5, with a sample size of 235 8-hour Time Weighted Average personal noise exposure measurement results recorded over the measurement period. The sample with the largest 8-hour Time Weighted Average personal noise exposure measurement result was also recorded within Platinum Concentrator Operation No. 5, with an 8-hour Time Weighted Average personal noise exposure measurement result of 101.9dBA.

The descriptive statistical data analysis of the 8-hour Time Weighted Average personal noise exposure measurement, grouped per Platinum Concentrator Operation further indicate that the 90th percentile 8-hour Time Weighted Average personal noise exposure measurement statistics ranged between 89.8dBA and 93.5dBA, with Platinum Concentrator Operation No. 4 returning the largest 90th percentile 8-hour Time Weighted Average personal noise exposure measurement statistical result of 93.5dBA. This represent an over exposure of almost 400%, when compared to the South African Occupational Exposure Limit of 85dBA (10).

The descriptive statistical analysis results, grouped per Platinum Concentrator Operation are displayed in Table 4.

Table 4. Descriptive statistical data analysis of the personal noise exposure, grouped according to Operation, for the five Concentrator Operations.

Operation	Number of samples	Minimum	Maximum	Median & Inter Quartile Range	Geometric Mean	Geometric Standard Deviation	90th Percentile
Concentrator Operation No.1	62	77.3dBA	92.5dBA	85.45dBA (83.5; 88.2)	85.52dBA	1.038dBA	89.4dBA
Concentrator Operation No.2	45	71.2dBA	98.9dBA	85.4dBA (81.4; 88.0)	84.75dBA	1.063dBA	91.9dBA
Concentrator Operation No.3	154	72.6dBA	104.7dBA	85.7dBA (82.6; 88.2)	85.21dBA	1.053dBA	90.1dBA
Concentrator Operation No.4	204	65.6dBA	99.5dBA	87.45dBA (85.6; 90.6)	87.63dBA	1.057dBA	93.5dBA
Concentrator Operation No.5	235	75.1dBA	101.9dBA	86.9dBA (83.8; 89.7)	86.51dBA	1.055dBA	92.5dBA

Figure 4 below further demonstrates the amount of the 8-hour Time Weighted Average personal noise exposure measurements which returned results in excess of the South African Occupational Exposure Limit of 85dBA, clearly highlighting the significance of the NIHL risk within the five Platinum Concentrator Operations (21).

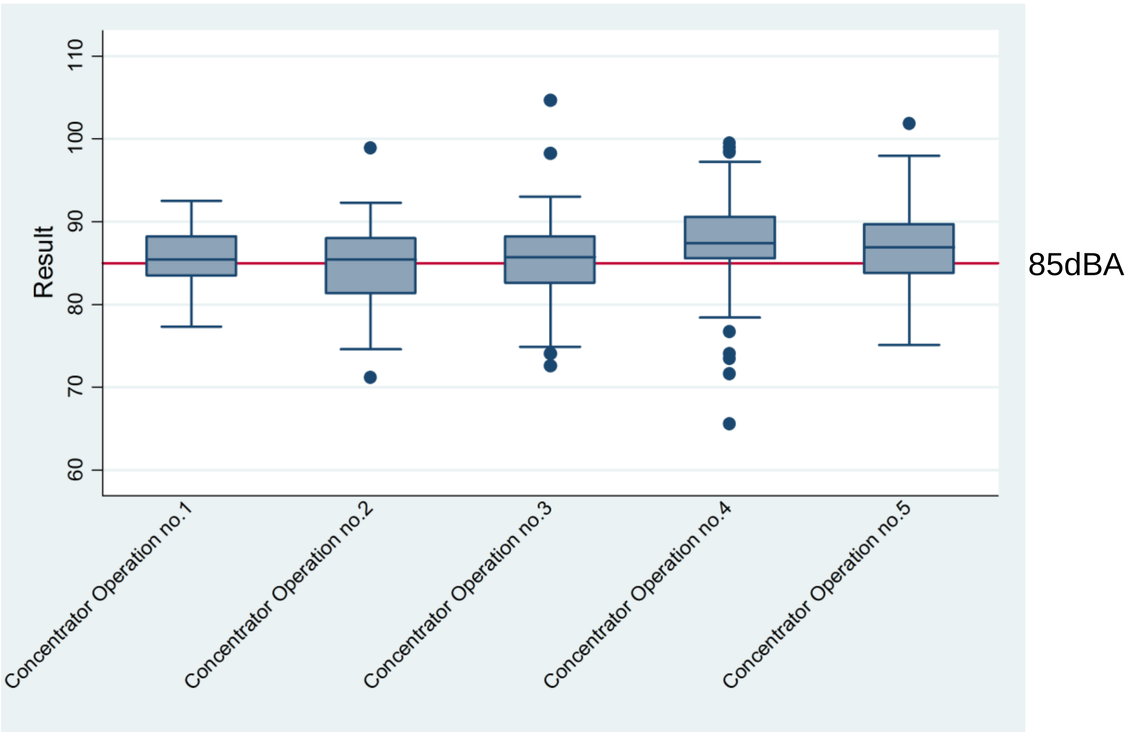

Figure 4: Box and Whisker plot of the personal noise exposure measurement results, grouped per Concentrator Operation.

The descriptive statistical data analysis of the 8-hour Time Weighted Average personal noise exposure measurement results, grouped according to Activity Area, revealed that the largest number of samples was conducted within the Roving Plant Activity area, with a sample size of 318 8-hour Time Weighted Average personal noise exposure measurement results recorded over the measurement period. The sample with the largest 8-hour Time Weighted Average personal noise exposure measurement result was however recorded within the crushing and Screening Activity Area, with an 8-hour Time Weighted Average personal noise exposure measurement result of 104.7dBA.

The descriptive statistical data analysis of the 8-hour Time Weighted Average personal noise exposure measurement, grouped per Activity Area further indicate that the 90th percentile 8-hour Time Weighted Average personal noise exposure measurement statistics ranged between 90.8dBA and 93.5dBA, with the Milling Activity Area returning the largest 90th percentile 8-hour Time Weighted Average personal noise exposure measurement statistical result of 93.5dBA. These results concur with the conclusion made by other researchers, stipulating that mineral processing plants tending to emit high noise levels (8).

The statistical analysis of the 8-hour Time Weighted Average personal noise exposure measurement results, grouped according to activity area, revealed that the Milling activity area returned the highest 90th Percentile result of 93.5dBA, followed by the Crushing and Screening activity area with a 90th Percentile result of 92.5dBA. These results suggests a direct relationship between the equipment or area noise measurement results and the 8-hour Time Weighted Average personal noise exposure measurement results, suggesting that employees are required to spend long periods of their working shift in these noisy areas.

The descriptive statistical analysis results, grouped per Concentrator Operation are displayed in Table 5.

Table 5. Descriptive statistical data analysis of the personal noise exposure, grouped according to Activity Area, for the five Concentrator Operations.

Activity Area	Number of samples	Minimum	Maximum	Median & Inter Quartile Range	Geometric Mean	Geometric Standard Deviation	90th Percentile
Crushing & Screening Areas	123	65.6dBA	104.7dBA	86.7dBA (83.5; 91.0)	85.85dBA	1.065dBA	92.5dBA
Milling Areas	120	74.6dBA	99.0dBA	88.1dBA (85.7; 91.25)	87.33dBA	1.053dBA	93.5dBA
Concentrating (Flotation & Thickening) Areas	139	77.4dBA	94.8dBA	87.2dBA (85.3; 88.9)	86.39dBA	1.039dBA	90.8dBA
Roving Plant Areas	318	71.2dBA	101.9dBA	85.9dBA (82.7; 88.2)	85.23dBA	1.056dBA	90.9dBA

Figure 5 below clearly demonstrates the magnitude of the noise exposure risk within the four Activity Areas, with more than 50% of all the 8-hour Time Weighted Average personal noise exposure measurements returning results in excess of the South African Occupational Exposure Limit of 85dBA, clearly highlighting the significance of the NIHL risk within the five Platinum Concentrator Operations (21).

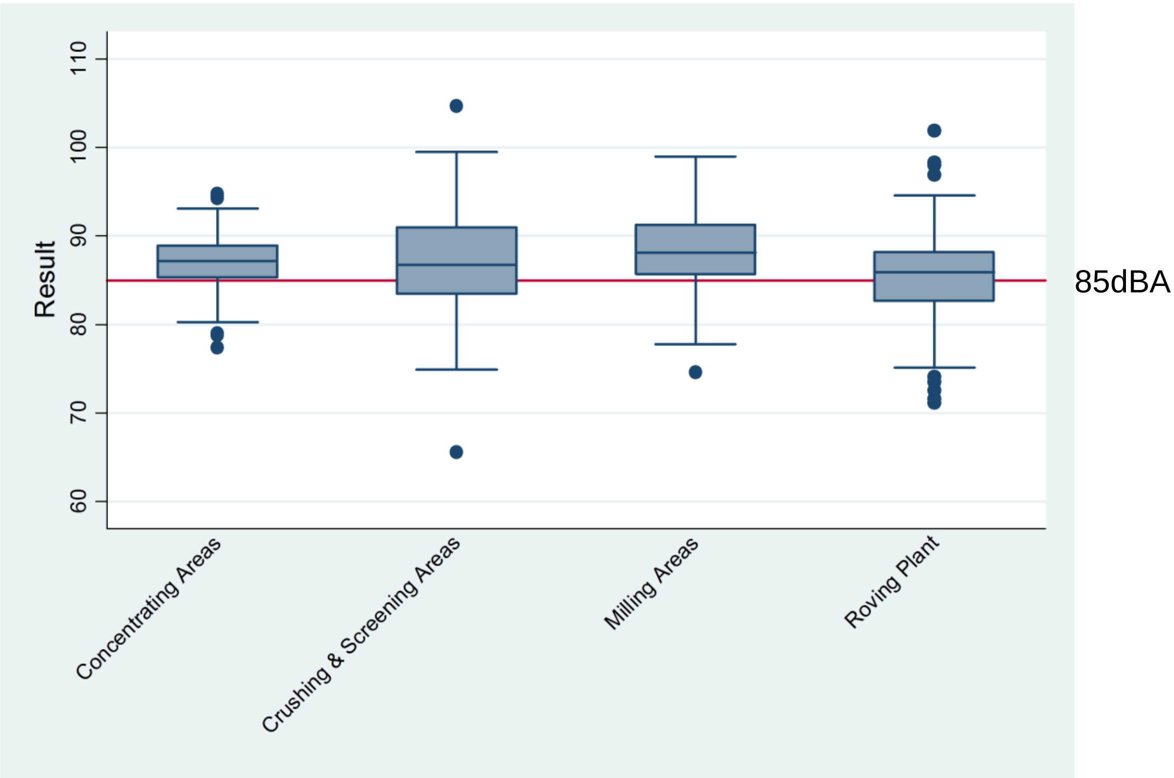

Figure 5: Box and Whisker plot of the personal noise exposure measurement results, grouped according to Activity Area for the five Concentrator Operations.

The descriptive statistical data analysis of the 8-hour Time Weighted Average personal noise exposure measurement results, grouped according to Occupation, revealed that the largest number of samples was conducted for the Processor Grade 3 Occupation, with a sample size of 136 8-hour Time Weighted Average personal noise exposure measurement results recorded over the measurement period.

The sample with the largest 8-hour Time Weighted Average personal noise exposure measurement result was however recorded within the Processor Grade 2 Occupation, with an 8-hour Time Weighted Average personal noise exposure measurement result of 104.7dBA. The Processor Grade 1, Processor Grade 2 and Processor Grade 3 Occupations perform the same work tasks, with the only difference being the level of competence of the persons. The workers employed in these occupations would therefore have a very high risk of developing NIHL, due to exposure to high energy noise sources for long periods of time, as part of their routine work activities (21).

The descriptive statistical data analysis of the 8-hour Time Weighted Average personal noise exposure measurement, grouped per Occupation further indicate that the 90th percentile 8-hour Time Weighted Average personal noise exposure measurement statistics ranged between 78.3dBA and 94.6dBA, with the Engineering Learner returning the largest 90th percentile 8-hour Time Weighted Average personal noise exposure measurement statistical result of 94.6dBA.

The descriptive statistical analysis results, grouped per Occupation are displayed in Table 6.

Table 6. Descriptive statistical data analysis of the personal noise exposure, grouped according to Occupation, for the five Concentrator Operations.

Occupation	Number of samples	Minimum	Maximum	Median & Inter Quartile Range	Geometric Mean	Geometric Standard Deviation	90th Percentile
Boilermaker Assistant	5	83.9dBA	93.2dBA	90.9dBA (85.1; 93.1)	89.15dBA	1.051dBA	93.2dBA
Boilermaker Plater	16	73.5dBA	98.3dBA	83.9dBA (78.95; 89.3)	84.01dBA	1.058dBA	91.8dBA
Carpenter	1	79.3dBA	79.3dBA	79.3dBA	79.3dBA	-	79.3dBA
Civil Engineering Worker	1	84.5dBA	84.5dBA	84.5dBA	84.5dBA	-	84.5dBA
Control Room Operator	5	72.6dBA	92.7dBA	75.9dBA (75.8; 81.6)	79.41dBA	1.057dBA	92.7dBA
Electrician	8	74.1dBA	91,9dBA	87.3dBA (80.15; 88.8)	84.61 dB	1.056dBA	91.9dBA
Engineering Assistant	84	75.1dBA	98.0dBA	85.9dBA (82.7; 87.9)	85.24dBA	1.056dBA	89.8dBA
Engineering Learner	6	83.5dBA	94.6dBA	87.05dBA (84.2; 91.6)	87.91dBA	1.056dBA	94.6dBA
Fitter and Turner	12	76.0dBA	88.6dBA	85.8dBA (84.3; 86.8)	85.01dBA	1.057dBA	85.8dBA
Foreman Boilermaker Plater	1	83.2dBA	83.2dBA	83.2dBA	83.2dBA	-	83.2dBA
Foreman Electrician	3	80.9dBA	82.3dBA	81.7dBA (80.9; 82,3)	81.63dBA	1.055dBA	82.3dBA
Foreman Mechanical	1	88.2dBA	88.2dBA	88.2dBA	88.2dBA	-	88.2dBA
General Assistant	1	82.9dBA	82.9dBA	82.9dBA	82.9dBA	-	82.9dBA
Instrumentation Mechanician	5	81.9dBA	88.2dBA	85.4dBA (83.7; 85.4)	85.09dBA	1.053dBA	88.2dBA
Instrumentation Technician	3	77.8dBA	86.0dBA	79.8dBA (77.8; 86.0)	81.12dBA	1.051dBA	86.0dBA
Laboratory Processor	5	80.0dBA	91.4dBA	85.8dBA (81.4; 87.3)	85.08dBA	1.063dBA	91.4dBA

Occupation	Number of samples	Minimum	Maximum	Median & Inter Quartile Range	Geometric Mean	Geometric Standard Deviation	90th Percentile
Labourer / Plant Cleaner	114	77.3dBA	101.9dBA	86.5dBA (84.7; 89.1)	86.87dBA	1.056dBA	91.7dBA
Metallurgical Foreman	1	90.3dBA	90.3dBA	90.3dBA	90.3dBA	-	90.3dBA
Metallurgist	5	71.2dBA	86.0dBA	80.0dBA (79.7; 83.3)	79.87dBA	1.058dBA	86.0dBA
Mill Reliner	2	78.4dBA	87.3dBA	82.85dBA (78.4; 87.3)	82.73dBA	1.079dBA	87.3dBA
Millwright	3	83.8dBA	84.5dBA	84.2dBA (83.8; 84.5)	84.17dBA	1.050dBA	84.5dBA
Occupational Hygiene Assistant	1	78.3dBA	78.3dBA	78.3dBA	78.3dBA	-	78.3dBA
Painter	1	80.9dBA	80.9dBA	80.9dBA	80.9dBA	-	80.9dBA
Plant Mobile Equipment Driver	6	75.1dBA	83.9dBA	81.6dBA (75.1; 83.4)	80.03dBA	1.056dBA	83.9dBA
Process Supervisor	13	80.2dBA	90.6dBA	86.9dBA (85.2; 88.1)	86.27dBA	1.057dBA	89.9dBA
Processor Grade 1	124	74.6dBA	98.9dBA	87.0dBA (84.15; 88.75)	86.32dBA	1.056dBA	91.0dBA
Processor Grade 2	120	65.6dBA	104.7dBA	87.35dBA (85.05; 87.35)	87.4dBA	1.057dBA	93.1dBA
Processor Grade 3	136	78.4dBA	99.5dBA	88.3dBA (85.35; 91.0)	88.12dBA	1.056dBA	93.1dBA
Rigger Surface	1	92.0dBA	92.0dBA	92.0dBA	92.0dBA	-	92.0dBA
Safety Officer	3	78.5dBA	88.0dBA	78.8dBA (78.5; 88.0)	81.65dBA	1.052dBA	88.0dBA
Senior Instrumentation Mechanician	8	71.6dBA	83.5dBA	80.15dBA (77.45; 82.05)	76.02dBA	1.057dBA	83.5dBA
Shift Leader	5	74.1dBA	87.8dBA	85.0dBA (83.3; 85.5)	83.0dBA	1.056dBA	87.8dBA

All the Occupations with a sample size of less than 5 samples were excluded from the Box and Whisker plot (Figure 6) of the personal noise results, grouped according to occupation.

Figure 6 below clearly highlights the magnitude of the noise exposure risk of the Occupations within all the Activity Areas of the five Platinum Concentrator Operations, with 72% of the Occupations returning 8-hour Time Weighted Average personal noise exposure measurements results datasets with more than 50% of the results in the dataset, recorded in excess of the South African Occupational Exposure Limit of 85dBA, clearly supporting the theory that mineworkers are exposed to noise levels in excess of 85dBA on a regular basis (20).

The Box and Whisker plot below describes the personal noise exposure measurement results, grouped according to the Occupations within the five Concentrator Operations, compared to the South African Occupational Exposure limit of 85dBA.

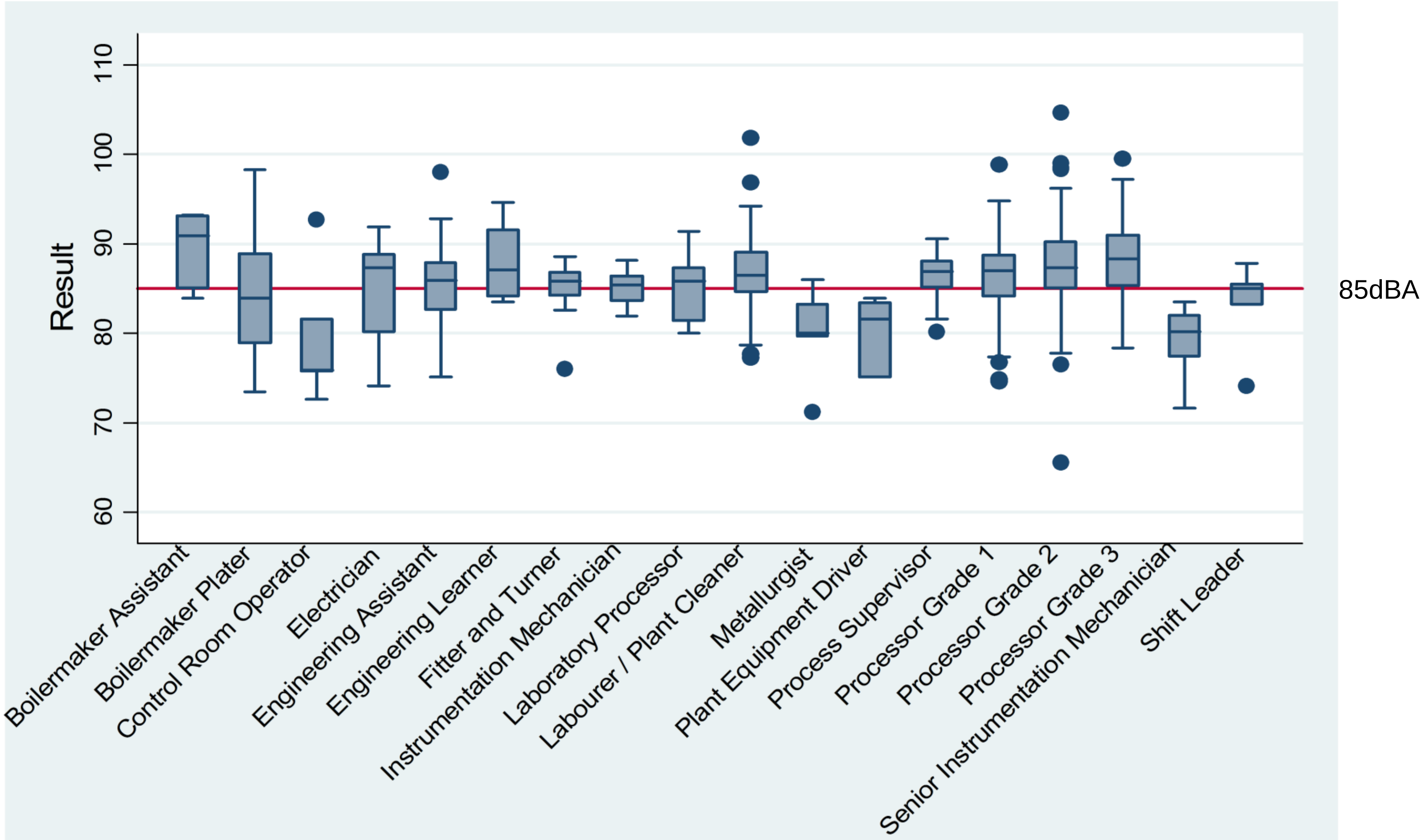

Figure 6: Box and Whisker plot of the personal noise exposure measurement results, grouped according to the Occupations within the five Concentrator Operations.

Figure 7 below depicts the close relationship of the noise exposure between the Processor Occupations, within the Crushing Activity Area of the five Concentrator Operations, demonstrating that the same tasks are performed by these occupations within the Activity area.

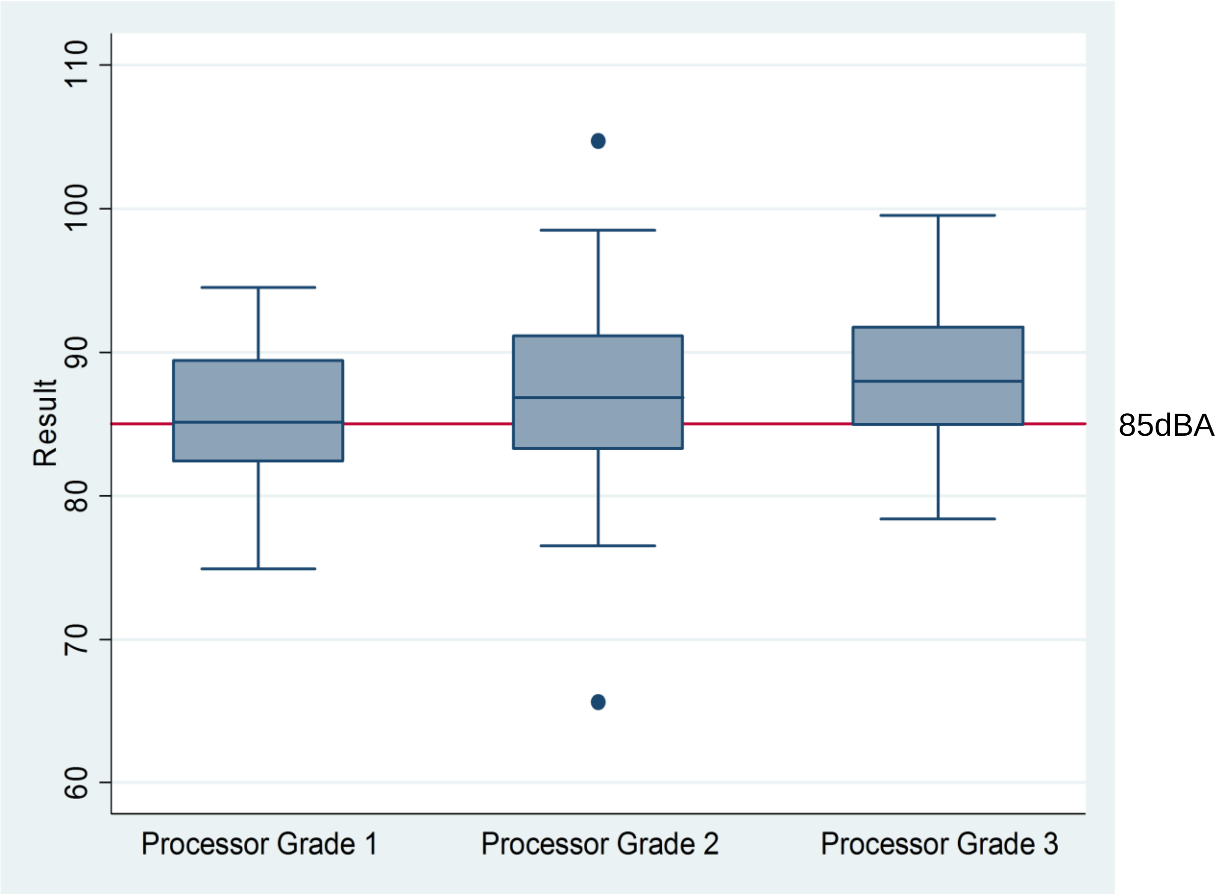

Figure 7: Box and Whisker plot of the personal noise exposure measurement results, grouped according to Occupation within the Crushing Activity Area of the five Concentrator Operations.

Figure 8 below depicts the close relationship of the noise exposure between the Processor Occupations, within the Milling Activity Area of the five Concentrator Operations, demonstrating that the same tasks are performed by these occupations within the Activity area.

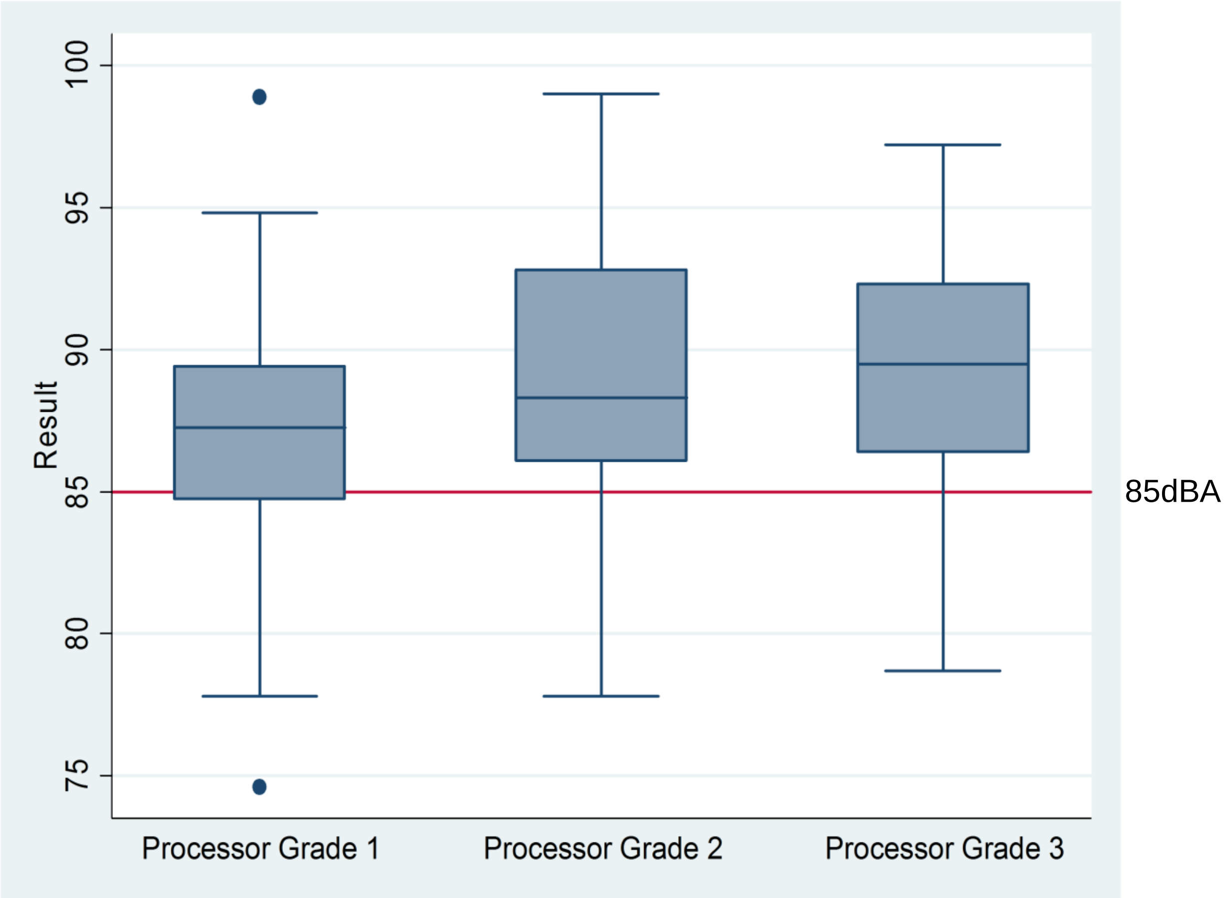

Figure 8: Box and Whisker plot of the personal noise exposure measurement results, grouped according to Occupation within the Milling Activity Area of the five Concentrator Operations.

Figure 9 below depicts the close relationship of the noise exposure between the Processor Occupations, within the Concentrating Activity Area of the five Concentrator Operations, demonstrating that the same tasks are performed by these occupations within the Activity area.

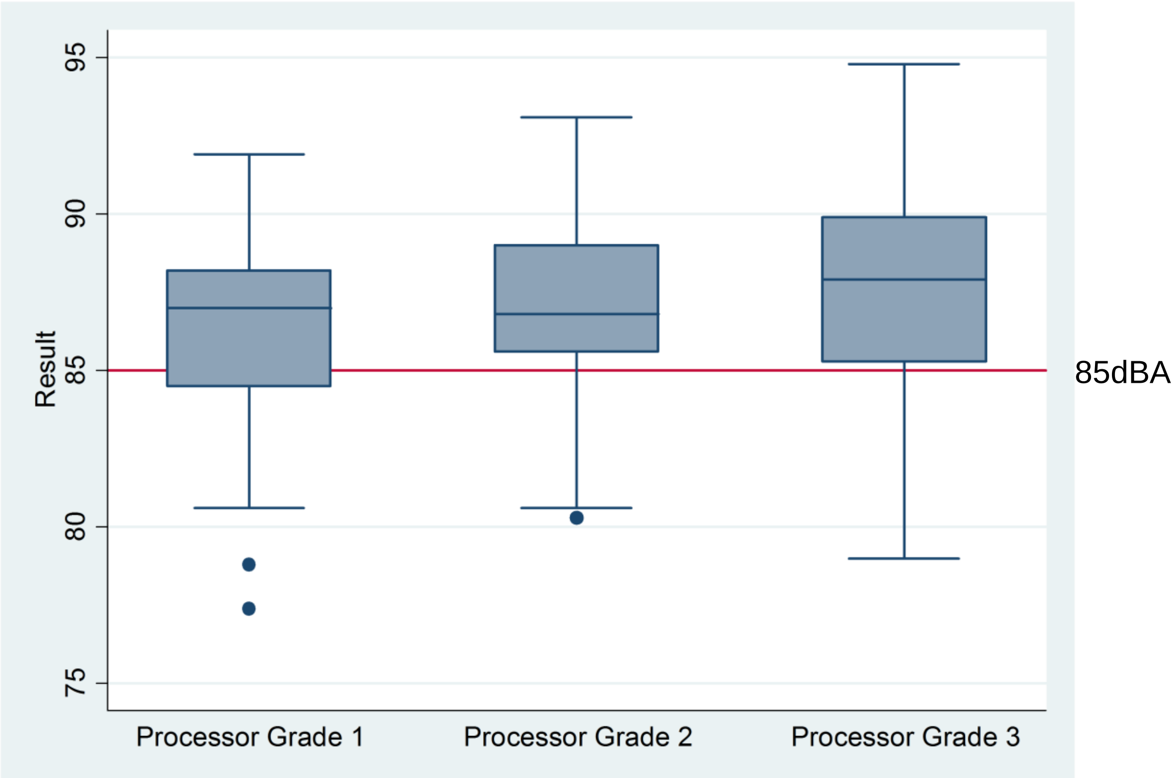

Figure 9: Box and Whisker plot of the personal noise exposure measurement results, grouped according to Occupation within the Concentrating Activity Area of the five Concentrator Operations.

All the Occupations with a sample size of less than 5 samples were excluded from the Box and Whisker plot (Figure 10) of the personal noise results, grouped according to occupation.

Figure 10 below clearly highlights the magnitude of the noise exposure risk of the Occupations within the Roving Activity Area of the five Platinum Concentrator Operations, with 73% of the Occupations returning 8-hour Time Weighted Average personal noise exposure measurements results datasets with more than 50% of the results in the dataset, recorded in excess of the South African Occupational Exposure Limit of 85dBA, clearly supporting the theory that mineworkers are exposed to noise levels in excess of 85dBA on a regular basis (20).

A Box and Whisker plot was compiled, to graphically display the noise measurement results, grouped according to the Occupations within the Roving Activity Area of the five Concentrator Operations, compared to the South African Occupational Exposure limit of 85dBA.

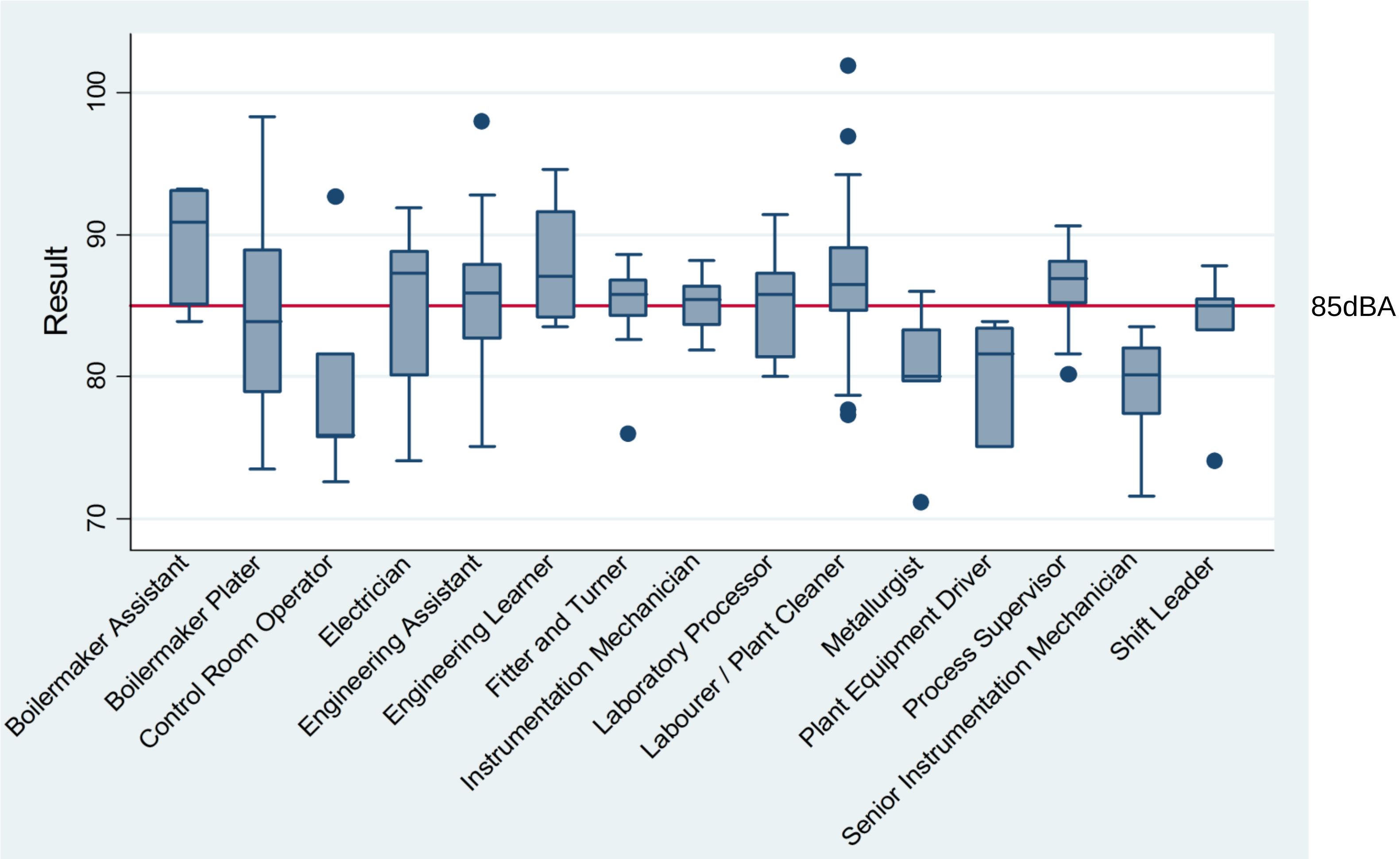

Figure 10: Box and Whisker plot of the personal noise exposure measurement results, grouped according to Occupation within the Roving Activity Area of the five Concentrator Operations.

This study also found that the age of the Platinum Concentrator Operation played a role in the level of the 8-hour Time Weighted Average personal noise exposure measurements recorded for each Platinum Concentrator Operation, with lower 8-hour Time Weighted Average personal noise exposure measurements recorded within the Platinum Concentrator Operations constructed post the year of 2000. Table 7 below demonstrates this phenomenon, where the personal noise exposures recorded within Concentrator Operations no.1; 2 and 3 are lower than the personal noise exposures within Concentrator Operations no.4 and 5.

Table 7. Comparison of personal noise exposure results, based on the age of the Platinum Concentrator Operation.

Operation	Median & Inter Quartile Range	Geometric Mean	Geometric Standard Deviation	90th Percentile
Concentrator Operation No.1 (Constructed post 2000)	85.45dBA (83.5; 88.2)	85.52dBA	1.038dBA	89.4dBA
Concentrator Operation No.2 (Constructed post 2000)	85.4dBA (81.4; 88.0)	84.75dBA	1.063dBA	91.9dBA
Concentrator Operation No.3 (Constructed post 2000)	85.7dBA (82.6; 88.2)	85.21dBA	1.053dBA	90.1dBA
Concentrator Operation No.4 (Constructed pre 2000)	87.45dBA (85.6; 90.6)	87.63dBA	1.057dBA	93.5dBA
Concentrator Operation No.5 (Constructed pre 2000)	86.9dBA (83.8; 89.7)	86.51dBA	1.055dBA	92.5dBA

3.2. Analysis of Variance between Groups (ANOVA)

3.2.1. The results of the ANOVA test performed per Operation:

For the first hypothesis test, the data collected was sorted according to Operation and an ANOVA test was performed on the data. The ANOVA test revealed a P-value of < 0.0001.

Table 8. ANOVA test results of the personal noise exposure measurement data, grouped according to Operation, for the five Concentrator Operations.

Number of observations =	700	R-squared =	0.0474
Root MSE =	4.529	Adj R-squared =	0.0419

Source	Partial SS	df	MS	F	Prob > F
Difference among Operation	709.2931	4	177.3233	8.64	< 0.0001
Difference within Operation	14255.76	695	20.51189		

3.2.1.1. Tukey HSD pairwise comparison between Operations:

The results of the ANOVA test was utilized to perform a Tukey HSD pairwise comparison, in order to determine which Concentrator Operations' noise results are statistically significantly different.

Table 9. Tukey HSD pairwise comparison results of the personal noise exposure measurement data, grouped according to Operation, for the five Concentrator Operations.

Studentized range critical value (.05, 5, 695) = 3.8678531
Harmonic mean sample size used = 92.589

Group	vs.	Group	Group means		mean dif	HSD-test
Concentrator Operation 1	vs.	Concentrator Operation 2	85.5758	84.9067	0.6691	1.4217
Concentrator Operation 1	vs.	Concentrator Operation 3	85.5758	85.3201	0.2557	0.5432
Concentrator Operation 1	vs.	Concentrator Operation 4	85.5758	87.7603	2.1845	4.6412*
Concentrator Operation 1	vs.	Concentrator Operation 5	85.5758	86.6362	1.0604	2.2528
Concentrator Operation 2	vs.	Concentrator Operation 3	84.9067	85.3201	0.4135	0.8784
Concentrator Operation 2	vs.	Concentrator Operation 4	84.9067	87.7603	2.8536	6.0628*
Concentrator Operation 2	vs.	Concentrator Operation 5	84.9067	86.6362	1.7295	3.6745
Concentrator Operation 3	vs.	Concentrator Operation 4	85.3201	87.7603	2.4402	5.1844*
Concentrator Operation 3	vs.	Concentrator Operation 5	85.3201	86.6362	1.316	2.7961
Concentrator Operation 4	vs.	Concentrator Operation 5	87.7603	86.6362	1.1241	2.3883

Rows marked with a * in the HSD-test column indicates a statistically significant difference

3.2.2. The results of the ANOVA test performed per Activity Area:

For the second hypothesis test, the data collected was sorted according to the Activity Areas within the five Concentrator Operations and an ANOVA test was performed on the data. The ANOVA test revealed a P-value of < 0.0001.

Table 10. ANOVA test results of the personal noise exposure measurement data, grouped according to Activity Area, for the five Concentrator Operations.

Number of observations = 700 R-squared = 0.0569
Root MSE = 4.50313 Adj R-squared = 0.0528

Source	Partial SS	df	MS	F	Prob > F
Difference among Activity Area	851.4345	3	283.8115	14	< 0.0001
Difference within Activity Area	14113.62	696	20.27819		

3.2.2.1. Tukey HSD pairwise comparison between Operations:

The results of the ANOVA test was utilized to perform a Tukey HSD pairwise comparison, in order to determine which Activity areas' noise results are statistically significantly different.

Table 11. Tukey HSD pairwise comparison results of the personal noise exposure measurement data, grouped according to Activity Area, for the five Concentrator Operations.

Studentized range critical value (.05, 4, 696) = 3.642143
Harmonic mean sample size used = 149.241

Group	vs.	Group	Group means		mean dif	HSD-test
Concentrator Operation 1	vs.	Concentrator Operation 2	87.0108	86.9902	0.0205	0.0557
Concentrator Operation 1	vs.	Concentrator Operation 3	87.0108	88.2567	1.2459	3.3799
Concentrator Operation 1	vs.	Concentrator Operation 4	87.0108	85.3563	1.6545	4.4885*
Concentrator Operation 2	vs.	Concentrator Operation 3	86.9902	88.2567	1.2664	3.4356
Concentrator Operation 2	vs.	Concentrator Operation 4	86.9902	85.3563	1.634	4.4327*
Concentrator Operation 3	vs.	Concentrator Operation 4	88.2567	85.3563	2.9004	7.8684*

Rows marked with a * in the HSD-test column indicates a statistically significant difference

3.3. Comparison of Results to Statutory Limits

The personal noise measurement results recorded for all five of the Platinum Concentrator Operations were compared to the South African Occupational Exposure Limit, as well as the OSHA Occupational Exposure Limit.

3.3.1. Personal noise exposure measurement results compared to the South African Occupational Exposure Limit:

33.43% of the personal noise measurement results recorded within the five Concentrator Operations returned results which were below the South African Exposure Limit of 85dBA.

66.57% of the personal noise measurement results recorded within the five Concentrator Operations returned results which were equal to and above the South African Exposure Limit of 85dBA.

234 of the personal noise measurement results recorded within the five Concentrator Operations returned results which were below the South African Exposure Limit of 85dBA.

466 of the personal noise measurement results recorded within the five Concentrator Operations returned results which were equal to and above the South African Exposure Limit of 85dBA.

3.3.2. Personal noise exposure measurement results compared to the OSHA Exposure Limit:

80.29% of the personal noise measurement results recorded within the five Concentrator Operations returned results which were below the OSHA Exposure Limit of 90dBA.

19.71% of the personal noise measurement results recorded within the five Concentrator Operations returned results which were in excess of the OSHA Exposure Limit of 90dBA.

562 of the personal noise measurement results recorded within the five Concentrator Operations returned results which were below the OSHA Exposure Limit of 90dBA.

138 of the personal noise measurement results recorded within the five Concentrator Operations returned results which were equal to and above the OSHA Exposure Limit of 90dBA.

Table 12. Personal noise exposure measurement results compared to Occupational Exposure Limits.

Aspect compared	Result
Number of personal noise measurements with results ≤85dBA	234
Number of personal noise measurements with results ≥85dBA	466
Percentage of personal noise measurements with results ≤85dBA	33.43%
Percentage of personal noise measurements with results ≥85dBA	66.57%
Number of personal noise measurements with results ≤90dBA	562
Number of personal noise measurements with results ≥90dBA	138
Percentage of personal noise measurements with results ≤90dBA	80.29%
Percentage of personal noise measurements with results ≥90dBA	19.71%

Figure 11 below graphically depict that between 50% and 75% of all the 8-hour Time Weighted Average personal noise exposure measurements results conducted between 2012 and 2014 returned measurement results which were in excess of the South African Occupational Exposure Limit of 85dBA.

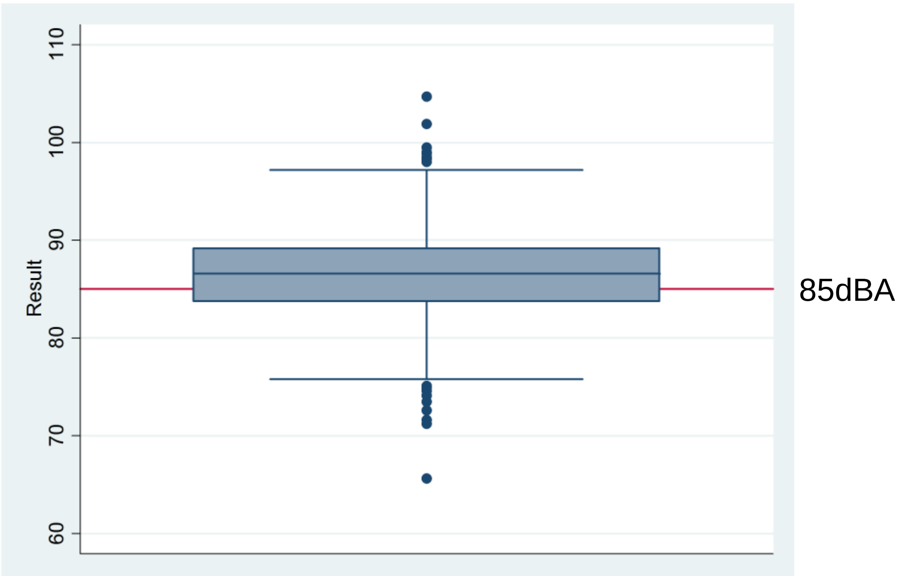

Figure 11: Box and Whisker plot of the personal noise exposure measurement results of the five Concentrator Operations, compared to the South African Occupational Exposure Limit.

Figure 11 below graphically depict that less than 25% of all the 8-hour Time Weighted Average personal noise exposure measurements results conducted between 2012 and 2014 returned measurement results which were in excess of the OSHA Occupational Exposure Limit of 90dBA

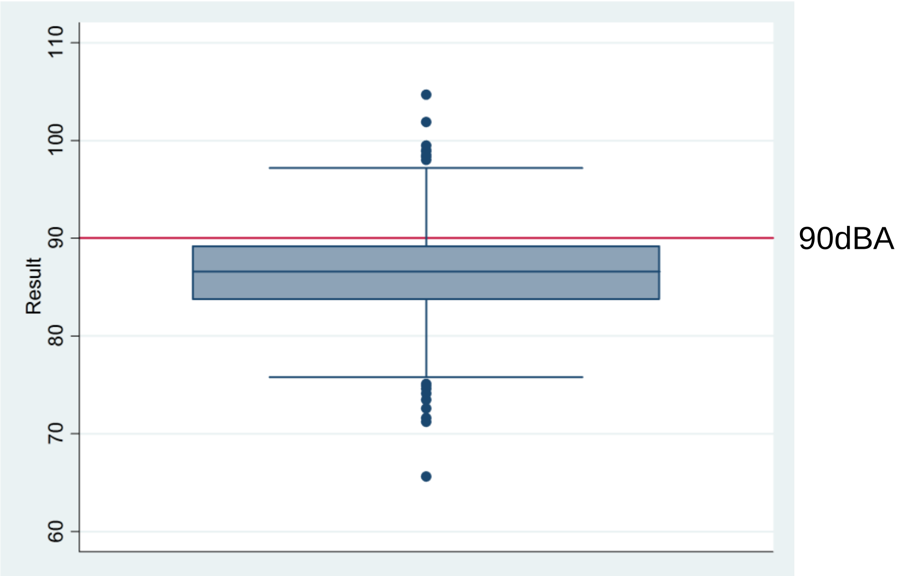

Figure 12: Box and Whisker plot of the personal noise exposure measurement results of the five Concentrator Operations, compared to the OSHA Occupational Exposure Limit.

CHAPTER 4 - DISCUSSIONOF RESULTS

4.1. Results of the Descriptive Statistical Analysis:

The literature review suggested that the mining industry employs a significant amount of ore winning processes which are inherently noisy and that the workers employed within the mining industry are at risk of developing NIHL (4, 21).

The statistical analysis of the data confirmed the suggestion of ore winning processes within the Mining industry as being noisy, with the statistical data analysis results revealing that the 90th Percentile of the 8-hour Time Weighted Average personal noise exposure measurements conducted at all five of the Concentrator Operations, which formed part of this study, were in excess of the South African Occupational Exposure Limit of 85dBA. Concentrator Operation No. 4 returned the highest 90th percentile 8-hour Time Weighted Average personal noise exposure measurement of 93.5dBA. It could therefore be concluded that Concentrator Operation No.4 would present the highest risk to employees developing NIHL, as a result of the most significant statistical results reported for the Median, Geometric Mean, as well as the 90th Percentile.

Further analysis of the 8-hour Time Weighted Average personal noise exposure measurements conducted at the Concentrator Operations revealed that a significant amount of the 8-hour Time Weighted Average personal noise exposure measurements returned results in excess of the South African Occupational Exposure Limit of 85dBA, with more than 50% of the personal noise measurements returning a 8-hour Time Weighted Average personal noise exposure measurement result of in excess of the South African Occupational Exposure Limit of 85dBA.

This outcome reiterates the suggestion of ore winning processes within the Mining industry as being noisy. This analysis again confirmed the conclusion of Concentrator Operation No.4 presenting the highest risk to employees for the development of NIHL, with more than 75% of the 8-hour Time Weighted Average personal noise exposure measurements returning results in excess of the South African Occupational Exposure Limit of 85dBA.

A study focusing on equipment or area noise measurements, conducted by El Dib *et al* concluded that large, high energy equipment, such as large vibrating screens; crushers and mills, installed at mineral processing plants tended to emit high noise levels (8).

The statistical analysis of the 8-hour Time Weighted Average personal noise exposure measurement results, grouped according to activity area, revealed that the Milling activity area returned the highest 90th Percentile result of 93.5dBA, followed by the Crushing and Screening activity area with a 90th Percentile result of 92.5dBA. These results suggests a direct relationship between the equipment or area noise measurement results and the 8-hour Time Weighted Average personal noise exposure measurement results, suggesting that employees are required to spend long periods of their working shift in these noisy areas.

The study conducted by El Dib *et al* also reported noise levels of greater than 90dBA at vibrating screens and crushers (21). The statistical analysis of the 8-hour Time Weighted Average personal noise exposure measurement results of the Platinum Concentrator Operations confirm this finding, with the Crushing and Screening activity area returning a 90th Percentile statistical analysis result of 92.5dBA.

Further analysis of the 8-hour Time Weighted Average personal noise exposure measurements conducted at the Platinum Concentrator Operations, grouped per activity area, revealed that the most significant amount of 8-hour Time Weighted Average personal noise exposures were recorded in the Milling Activity area, with more than 75% of the of the 8-hour Time Weighted Average personal noise exposure measurements returning results in excess of the South African Occupational Exposure Limit of 85dBA.

The literature reviewed also suggested that a significant amount of mineworkers in the United States of America were exposed to noise levels in excess of 85dBA on a daily basis (20).

The statistical analysis of the 8-hour Time Weighted Average personal noise exposure measurements conducted at the Platinum Concentrator Operations, grouped per activity area, revealed that the majority of occupations within the five Platinum Concentrator Operations returned a 90th Percentile statistical analysis result in excess of the South African Occupational Exposure Limit of 85dBA, with front-line maintenance and all production occupations returning 90th Percentile statistical analysis results in excess of 90dBA.

The statistical analysis of the 8-hour Time Weighted Average personal noise exposure measurements concluded that the Engineering Learner; Boilermaker and Processor occupations were identified as the top three exposed occupations at the Platinum Concentrator Operations, with all three these occupations returning 90th Percentile statistical analysis results in excess of 93dBA. The workers employed in these three occupations would therefore have a very high risk of developing NIHL, due to exposure to high energy noise sources as part of their routine work activities.

More than 75% of the of the 8-hour Time Weighted Average personal noise exposure measurements results for the Boilermaker Assistant, Process Supervisor and Processor occupations were recorded to be in excess of the South African Occupational Exposure Limit of 85dBA. This information further highlights the very high risk of the employees employed in these occupations of developing NIHL.

This study also established a direct link between the age of the Concentrator Operation and the personal noise exposure results of the employees. The personal noise exposures of the employees working in newly constructed Concentrator operations were lower that the personal noise exposures of persons working in older Concentrator Operations.

4.2. Analysis of Variance between Groups (ANOVA) Analysis:

For the first test, the personal noise exposure measurements were grouped according to the five Concentrator operations. An ANOVA test was performed on the data, to determine whether there are statistically significant differences between the five Concentrator Operations. The ANOVA test revealed a P-value of < 0.0001, which indicates that there are statistically significant differences between the five Concentrator Operations. A Tukey HSD pairwise comparison was then performed on the data, to determine which of the five Concentrator Operations are statistically significantly different from each other. The Tukey HSD pairwise comparison indicated that there were statistically significant differences between Concentrator Operations 1 and 4; between Concentrator Operations 2 and 4; and between Concentrator Operations 3 and 4.

For the second test, the personal noise exposure measurements were grouped according to the four Activity Areas. An ANOVA test was performed on the data, to determine whether there are statistically significant differences between the four Activity Areas. The ANOVA test revealed a P-value of < 0.0001, which indicates that there are statistically significant differences between the four Activity Areas. A Tukey HSD pairwise comparison was then performed on the data, to determine which of the four Activity Areas are statistically significantly different from each other. The Tukey HSD pairwise comparison indicated that there were statistically significant differences between the Concentrating Activity Area and the Roving Activity area, as well as the Milling Activity Area and the Roving Activity area.

4.3. Comparison of personal noise exposure results to statutory limits:

66.57% of the employees sampled for personal noise within the five Concentrator Operations were over exposed to noise, when compared to the South African Exposure Limit, due to these personal noise measurement results being in excess of the South African Exposure Limit of 85dBA

In contrast, only 19.71% of the employees sampled for personal noise within the five Concentrator Operations were over exposed to noise, when compared to the OSHA Exposure Limit, due to these personal noise measurement results being in excess of the OSHA Exposure Limit of 90dBA.

CHAPTER 5 - CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions:

The objectives of this study were to describe personal noise exposure measurements of permanent and long term contractor employees during 2012 to 2014 at five Platinum Concentrator operations; to compare the personal noise exposure levels of the different activity areas between the five Platinum Concentrator operations; and to compare the personal noise exposure measurements of the Platinum Concentrator operations to national and international exposure limits.

This study demonstrated that the employees performing work in the Milling Activity area returned the highest personal noise exposure 90th Percentile statistical result of 93.5dBA and therefore would have a higher risk of developing NIHL, than the employees performing work in the other Activity Areas of the five Platinum Concentrator Operations. These employees performing their work in the Milling Activity Areas are also required to spend longer periods of their working shift in areas where the process operations are continuous, with a significant amount of electrical motors and pump assemblies concentrated in relatively confined areas. The Crushing and Screening Activity area on the other hand have less electrical motors and pump assemblies installed and the process is more of an intermittent process. The Crushing and Screening Activity Areas are also larger sections, requiring employees to "roam" between the areas and therefore spending some time away from the high energy noisy equipment and outside of the noisy areas (5).

This study further concluded that the Processor Grade 3 occupation were the production occupations, within the five Platinum Concentrator Operations, with the highest personal noise exposure 90th Percentile statistical result of 93.1dBA, followed by the Processor Grade 2 occupation with a personal noise exposure 90th Percentile statistical result of 93.1dBA,. The Processor Grade 1 occupation was the production occupation which returned the lowest personal noise exposure 90th Percentile statistical result of 91.0dBA. The process occupations are graded according to their level of competence, with a Processor Grade 3 having a higher level of competence than a Processor Grade 1. The difference in personal noise exposure between the process occupations could be attributed to the complexity of the process tasks the more competent employees are required to perform. The Processor Grade 3 Occupation would therefore have the highest risk of developing NIHL, compared to the Processor Grade 2 and Processor Grade 1 occupations.

The study further found that the Engineering Learner and Boilermaker Assistant occupations were the occupations within the Roving Plant Activity Area which returned the highest personal noise exposures, with personal noise exposure 90^{th} Percentile statistical results of 94.6dBA and 93.2dBA respectively. These occupations are exposed to high noise levels when performing maintenance tasks within the Crushing and Screening; Milling and Concentrating Activity Areas of the five Platinum Concentrator Operations. Some of these maintenance tasks are sometimes performed whilst some of the equipment is still in operation and are inherently noisy tasks, with the Boilermaker occupations also performing very noisy tasks of grinding, cutting and welding of steel. Some of the Engineering Learner employees are learners to become Boilermakers and would therefore have similar personal noise exposures than the Boilermakers.

This study also established a direct link between the age of the Platinum Concentrator Operation and the personal noise exposure results recorded for the employees. The 8-hour Time Weighted Average personal noise exposure measurement results of the employees working in newly constructed Concentrator operations were lower than the 8-hour Time Weighted Average personal noise exposure measurement results of employees working in older Concentrator Operations.

This study finally concluded that 66.57% of the employees sampled for personal noise within the five Concentrator Operations were over exposed to noise, when compared to the South African Exposure Limit of 85dBA. This result confirm that exposure to noise within the five Platinum Concentrator Operations is a high occupational health risk and highlights the need for additional noise control measures to be implemented, in order to reduce the risk of exposed employees developing NIHL.

5.2. Recommendations:

Effective control of noise would be achieved by following the hierarchy of control, when considering the control measures for the effective control of exposure to noise. The figure below, published by the NIOSH clearly demonstrates the application of the Hierarchy of control.

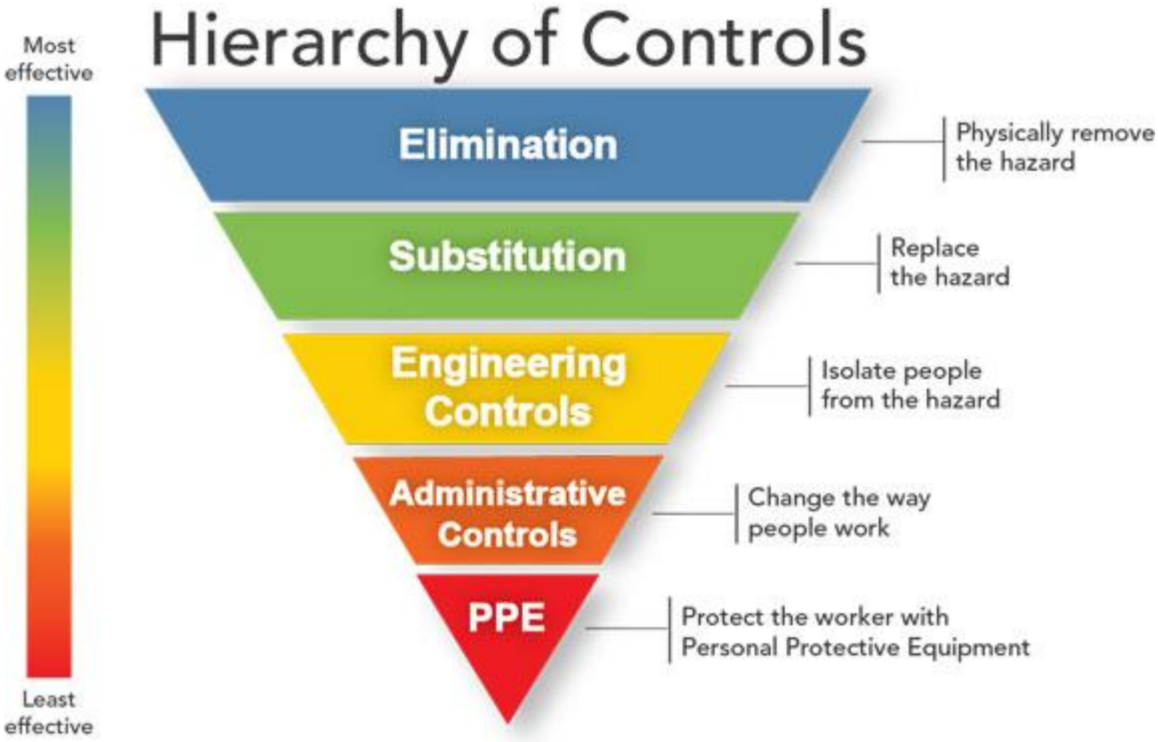

Figure 4: Hierarchy of controls (27).

The elimination and substitution type of controls are the most effective type of control, but are extremely difficult and expensive to implement in existing operations, whilst the Engineering, Administrative and PPE type of control would be more practical and economical solutions for existing operations, which should therefore constitute as the main focal areas of noise control for the Concentrator Operations(27).

In terms of engineering noise control, the management of the Concentrator Operations could consider replacing the perpendicular blade type of cooling fans installed on the electrical motors with directional blade type of cooling fans, which could result in a reduction in noise level of between 4dB to 6dB emitted at a distance of one meter from each electrical motor. This amount of noise reduction is quite significant, as a 3dB reduction in noise level represents a 50% reduction in sound intensity(1).

In terms of administrative noise control, the management of the Concentrator Operations could consider implementation or improvement of the following administrative noise control measures: Process automation / remote operation; adequate equipment maintenance; prompt reporting of noisy or defective equipment; and an effective hearing conservation programme.

Process automation / remote operation: The current working arrangements for the process staff at the Concentrator Operations involves a lot of time spent within the working places. The management of the Concentrator Operations should consider to further automate the Concentrator Operations, which would as a result, reduce the amount of tasks required to be performed within the Activity Areas of the Concentrator Operations, as well as the time required to be spent within the Activity Areas of the Concentrator Operations. This will have a direct impact in reducing the personal noise exposure of the production employees.

Adequate equipment maintenance: The Concentrating and Milling Activity contains a significant amount of high energy equipment, such as electrical motors and pumps, with several of these being v-belt driven equipment (20). The v-belts can create a lot of noise, if not tensioned properly, due to the slipping of the v-belts. A system of pro-active maintenance and the checking of v-belt tensions could eliminate the possibility of the slipping of v-belts, which would contribute to the reduction in the personal noise exposures of employees. A system of immediate reporting of defective and / or noisy equipment would also contribute to the reduction in the personal noise exposure of the employees. If defective and/ or noisy equipment, for example failed motor or pump bearings and slipping v-belts are promptly reported and rectified, to possibility of employees being exposed to these sources of high noise levels are then minimised or eliminated, which would also contribute to the reduction in personal noise exposures.

<u>An effective hearing conservation programme:</u> Another administrative control for the Concentrator Operations would be an effective hearing conservation programme, with the primary focus of engineering noise control.

OSHA determined that an effective hearing conservation programme consists of the following elements (28-30):

(1). An adequate employee noise exposure monitoring programme

(2). The implementation of effective noise control measures, with a primary focus of noise controls in the following order: Engineering noise controls, Work practices and other administrative control measures

(3). The provision of personal protective equipment with an adequate noise reduction rating, for employees exposed to noise levels in excess of the OEL

(4). An adequate training programme, in order to educate employees regarding the hazards of noise; the control measures implemented by the employer, including the limitations of these control measures and the reporting of defective implemented noise control measures

(5). A system of baseline and annual audiometric evaluations for all exposed employees

(6). A system of the investigation into identified shifts in hearing, which would primarily focus on the identification and rectification of the root cause of the shift in hearing, in order to prevent any further occupational hearing loss

(7). A detailed record keeping system, which includes the linking of noise exposure measurements to the system of medical surveillance implemented (28-30)

Considering the international best practice mentioned above, the management of the Concentrator Operations which formed part of this study should consider improving the following aspects, which would realise a significant improvement of the existing hearing conservation programmes of the Concentrator Operations:

(1). The implementation of effective noise control measures, with a primary focus on Engineering noise controls. The majority of the noise controls implemented within the Concentrator Operations did not consider Engineering noise control methods and rather focused on Administrative controls and Personal Protective Equipment.

(2). Ensuring that contractor employees make use of personal protective equipment with an adequate noise reduction rating, for exposure to noise levels in excess of the OEL. Systems to ensure that the permanent employees make use of personal protective equipment with an adequate noise reduction rating were well implemented at the Concentrator Operations, but these systems were not enforced upon the contractor employees. Adoption of the Hearing Protection Device_Training, Awareness and Selection_Tool (HPD_TAS_TOOL) Mining Occupational Safety and Health (MOSH) Leading Practice would also add a valuable contribution to the selection of the appropriate hearing protection for the noise risk of the company or operation.

(3). It would be valuable for the Concentrator Operations to enhance the training programme with the aim of educating employees on the limitations of the control measures implemented and encouraging the reporting of defective implemented noise control measures to management, for rectification. Adoption of the HPD_TAS_TOOL MOSH Leading Practice would also add a valuable contribution to the training programme, instilling improved awareness and knowledge pertaining to the noise risk.

(4). Enhancing the system of baseline and annual audiometric evaluations for exposed employees with a system of hearing protection validation testing, which could identify and provide for the opportunity to correct the incorrect fitment and selection of hearing protection devices.

(5). The record keeping system implemented could be enhanced with the addition of the hearing protection validation testing outcomes and actions taken, which could provide valuable evidence on ensuring that the correct type of hearing protection devices were issued / selected and correctly used.

Personal Protective Equipment: The use of hearing protection devices forms a significant part of the noise exposure protection strategy employed by the Concentrator Operations. The Concentrator Operations would benefit from the adoption of the HPD_TAS_TOOL MOSH Leading Practice. The HPD_TAS_TOOL would enhance the process of selecting the appropriate hearing protection device for the workers, based on the level of exposure to noise.

HPD_TAS_TOOL MOSH Leading Practice: The Learning Hub of the Chamber of Mines of South Africa Adoption developed the HPD_TAS_TOOL MOSH Leading Practice, with the objective of assisting the South African Mining Industry in realising the elimination of NIHL by improving the effectiveness of the hearing conservation programmes implemented. The tool aims to correct employee behaviour through the analysis of employee perceptions, also referred to as the mental models of employees, with regard to the noise risk. The outcome is that employees fully understand the hazard and risk and have a mental model consisting of a willingness to comply with the Leading Practice (4).

This tool includes technical aspects, as well as behavioural aspects, which would strengthen key aspects of the hearing conservation programme. The behavioural aspects mainly aim to improve the workers' knowledge of NIHL, awareness of noise as a hazard, as well as the improvement of workers' motivation to comply with the health and safety work practices of the company or operation. The technical aspects of the tool include the training materials on the correct use of hearing protection devices, as well as a hearing protection device selection tool which enables the selection of the correct hearing protection device for the noise risk of the company or operation (4).

In conclusion, despite recent legislative improvements in the Mine Health and Safety Act, employees working in the Mining Industry are still being exposed to high levels of noise in their working places. This study demonstrated that the majority of employees employed at Platinum Concentrator operations are exposed to noise levels in excess of the South African Exposure Limit of 85dBA, with the Median, Geometric Mean and 90th Percentile personal noise exposures for all five the Concentrator operations being in excess of the South African Exposure Limit of 85dBA. This highlights the need for further research on personal noise exposure in the platinum concentrator setting, especially on control of noise exposures within the South African Mining Industry.

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APPENDICES

APPENDIX 1 - Permission to conduct the study

MEMORANDUM

To	:	Richard Pilkington – General Manager: Concentrator Operations
From	:	Willie Deysel – Occupational Hygienist: Concentrator Operations
Date	:	21 January 2015
SUBJECT	:	**Request for permission to conduct a research study**

Dear Sir,

I am hereby requesting your permission, to conduct a research study, to compare the personal noise exposure measurements conducted on of the employees of the Anglo American Platinum Concentrator operations between the various Concentrator operations of Anglo American Platinum, as part of my Masters in Public Health: Occupational Hygiene studies at WITS University.

Exposures to noise at hazardous levels have been documented to result in Noise Induced Hearing Loss (NIHL), an occupational disease which is irreversible. The occupational exposure to noise has not yet been well documented for the Platinum processing industry.

This study aims to evaluate the personal occupational exposure to noise in Platinum Concentrator Plants.

The main objectives of my study include:

Objective 1: To describe the personal noise exposure measurement results recorded at the Platinum Concentrator Plants during the period of 2012 – 2013.

Objective 2: To compare the personal noise exposure measurement results of the various sections of the Platinum Concentrator Plants between the different Concentrator Plants.

Objective 3: To compare the personal noise exposure measurement results of the Platinum Concentrator Plants to national and international exposure limits.

I am planning on conducting this study at four Anglo American Platinum Concentrator operations situated in the Bushveld igneous Complex of South Africa and no mention of the company or location of the operations will be made in the study report.

Yours in Health and Safety

....

Willie Deysel
Occupational Hygienist: Concentrator Operations

Approved

....

Richard Pilkington
General Manager: Concentrator Operations

APPENDIX 2 - Ethics Clearance Certificate

R14/49 Mr Willem Deysel

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

CLEARANCE CERTIFICATE NO. M150640

NAME: (Principal Investigator)	Mr Willem Deysel
DEPARTMENT:	School of Public Health Anglo American Platinum
PROJECT TITLE:	Personal Noise Exposure in the Bushveld Complex of South Africa
DATE CONSIDERED:	26/06/2015
DECISION:	Approved unconditionally
CONDITIONS:	
SUPERVISOR:	Dr Andrew Swanepoel
APPROVED BY:	Professor P Cleaton-Jones, Chairperson, HREC (Medical)
DATE OF APPROVAL:	15/07/2015

This clearance certificate is valid for 5 years from date of approval. Extension may be applied for.

DECLARATION OF INVESTIGATORS

To be completed in duplicate and **ONE COPY** returned to the Secretary in Room 10004, 10th floor, Senate House, University.
I/we fully understand the conditions under which I am/we are authorized to carry out the above-mentioned research and I/we undertake to ensure compliance with these conditions. Should any departure be contemplated, from the research protocol as approved, I/we undertake to resubmit the application to the Committee. **I agree to submit a yearly progress report**.

Principal Investigator Signature

Date 04 /08/2015

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES