OCCUPATIONAL NOISE EXPOSURE AMONG GROUNDSKEEPERS AT A PUBLIC UNIVERSITY IN GAUTENG, SOUTH AFRICA

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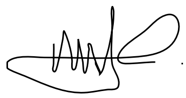
Declaration

I, **Moses Mokone (student number: 1818890)**, declare that the research project entitled *"Occupational noise exposure among groundskeepers at a public university in Gauteng, South Africa"* is my research work undertaken under the supervision of Dr Masilu Daniel Masekameni and Mr Oscar Rikhotso. The work is being submitted in partial fulfilment for the degree of Master of Public Health in the field of Occupational Hygiene at the School of Public Health, University of the Witwatersrand, Johannesburg. This work has not been presented for examination at any other university. The author designed the study, carried out all field data collection, data analysis, and wrote the research report. Parts of this research report have been planned to be published in peer-reviewed journals and presented at conferences. All the sources cited in this study have been acknowledged through comprehensive references. The senate plagiarism policy is signed and attached as an Appendix A: Plagiarism Declaration Form.

 28/04/2023

Dedication

This study is dedicated to the Lord our Almighty for his grace and protection throughout this study. I also dedicate this study to my loving family, friends and everyone who supported and encouraged me from the beginning to the end of this research study. This study is dedicated to all those individuals who have suffered hearing loss on and off the job as a result of excessive exposure to noise.

Abstract

Background

There is sufficient scientific evidence indicating that excessive and prolonged exposure to noise causes noise-induced hearing loss (NIHL), also known as permanent hearing loss and other non-auditory effects such as sleep disturbance, hypertension, and interference with the nervous and cardiovascular systems. The World Health Organization (WHO) estimated that NIHL costs approximately 0.2% to 2% of the gross domestic product (GDP) of the developed nations in terms of compensation and economic burden on society. It also estimated that more than 16% of the NIHL in adults is attributable to occupational noise exposure. Although preventable, NIHL is one of the most widespread irreversible occupational disease worldwide and thus was declared as a serious occupational hazard.

Worldwide, occupational noise exposure is widely regulated and most countries, including South Africa, use 85 dBA as the occupational exposure limit for noise exposure and has adopted the 3-dB exchange rate, with the exception of the US and Brazil, amongst others, which use the 5-dB exchange rate rule. Exchange Rate is the increase in noise level that corresponds to a doubling of the noise level. A few countries around the world such as the US, Japan and India use 90 dBA as a regulated limit for noise exposure. Acute hearing loss can also occur suddenly if a person is exposed to very high impact noise (above 140 dBC) for a short duration such as explosion and gun shots. Research shows that 8-hour average daily noise exposure levels between 75 dBA and 80 dBA are unlikely to cause hearing loss. The International Organization for Standardization (ISO 1999) “Acoustics - Determination of Occupational Noise Exposure and Estimation of Noise-Induced Hearing Impairment” provides damage risk criterion information that enable the prediction of NIHL at various audiometric frequencies and for varying exposure durations. Attempts to limit human exposure to noise are based on damage risk criterion. For example, the National Institute for Occupational Safety and Health (NIOSH) estimates a risk of NIHL after a 40-year working lifetime of 1% at 80 dBA, 8% at 85 dBA, and 25% at 90 dBA. This shows that the 85 dBA limit does not guarantee safety, since 85 dBA is already indication 8% excess risk.

The WHO has indicated that workers employed in sectors such as manufacturing, transportation, construction, mining, utility, agriculture and military have the highest risk of NIHL. In the Services sector, which include Garden and Landscaping services, the extensive

use of powered lawn maintenance machines results in widespread exposure to high levels of noise. The employees employed in the garden and landscaping sector such as groundskeepers, are in charge of maintaining general landscape of public and private areas such as sporting grounds, community parks and learning institutions grounds. Their main tasks involve a variety of outdoor activities such as clearing leaves, mowing lawns, cutting trees, trimming hedges, applying fertilizer, removing dead or unwanted plants and other general garden maintenance work. Noise exposure, which is one of the main health hazards that severely affect the health of these employees during operation of powered lawn maintenance machines such as leaf blowers, riding and push lawnmowers, brush-cutters and chainsaws can be a significant source of workplace noise exposure among groundskeepers.

Although the literature on occupational noise exposure has concentrated on large industrial sectors (mining, construction, manufacturing and transportation), the problem extends to smaller operations such as lawn maintenance. Recent literature suggests that noise generating activities in small-scale operations, such as lawn maintenance, use high noise emitting machinery.

Purpose

The purpose of this study was to evaluate occupational noise exposure levels of groundskeepers who operate different types of powered lawn maintenance machines at three campuses of a public university in Gauteng and estimate their risk of NIHL.

Methods

A quantitative, cross-sectional study design conducted among groundskeepers following a non-probability convenience sampling strategy was used. Personal and area noise exposure levels were evaluated in accordance with the South African National Standard (SANS) Code of Practice 10083:2013. The measurements for personal noise were conducted using a type 2 Casella dBbadges (personal noise dosimeters), which were placed on the groundskeepers' shoulders, close to the ear adjudged as receiving the highest noise levels covering sufficient time representative of daily (task-based) exposure. Area noise measurements were performed using a type 1 Quest integrating sound level meter (SLM), which was mounted on a tripod stand and placed at approximately 1.5 meters above the floor and 1 m from the noise generating machine. In each measurement position, one-minute measurements were completed, and A-weighted equivalent noise levels (LAeq) were recorded. To ensure accuracy of measurements, the noise measuring instruments were calibrated before and after each series of measurements using a calibrated portable acoustic calibrator as per the manufacturer's instructions. The SLM and personal noise dosimeters (PNDs) were calibrated using a type 1 acoustic calibrator (Model QC-10, Quest Technologies, USA) and type 2 acoustic calibrator (*Casella CEL 110/2, Regent House, Bedford, U.K*) respectively. No significant shift in calibration was detected for any individual measurement. All the noise measuring instruments were externally calibrated by a South African National Accreditation System (SANAS) 17025 accredited laboratory.

A questionnaire constructed by the primary researcher was utilized to record groundskeepers' demographic information, work processes pertaining to tasks performed and noise exposure levels, including certain elements of hearing conservation practices such as information and training, audiometric testing, and use of hearing protective devices (HPDs).

A total of 18 PND measurements and 17 area noise measurements were conducted at three university campuses i.e. Campus A, Campus B and Campus C. The noise measurements were conducted over a period of five (5) days (1-3 September 2021 and 3-4 November 2021).

Data/ readings from the noise monitoring instruments were manually recorded on predesigned field sheets and manually entered onto Microsoft Excel spreadsheet. Thereafter, a statistical analysis using a one-way analysis of variance (ANOVA) was carried out to determine whether a significant difference existed between the mean personal and area noise exposure levels measured at three university campuses. Formulas from the SANS 10083 standard were used to calculate measured noise levels for comparison with the regulated noise rating limit of 85 dBA using Microsoft Excel spreadsheet.

Results

The results of this study showed that majority, 78% (14 out 18), of groundskeepers' personal noise exposure levels (task-based) in the three campuses exceeded the legislated noise rating limit of 85 dBA, thus increasing groundskeepers' risk to NIHL. Groundskeepers in campus A were exposed to the highest eight-hour equivalent continuous A-weighted sound pressure level (LAeq, 8h) with mean noise levels of 91.5 dBA ±4.7, followed by campus B and C with mean noise levels of 89.1 dBA ±4.0 and 86.9 dBA ±2.9 respectively. Peak noise exposure levels (LCpeak) measured as part of personal noise exposure in the three campuses ranged from 115.6 dB to 140.0 dB. These excessive peak noise exposures are attributed to the types of machines used during lawn maintenance activities. The overall statistical difference in the mean personal noise exposure levels (LAeq, 8h) and peak levels (LCpeak) between the three campuses were found to be not significant for both the LAeq, 8h ($P = 0.304$) and LCpeak ($P = 0.607$).

Furthermore, majority, 71% (12 out 17), of area noise levels measured on specific lawn maintenance machines had equivalent continous A-weigted sound pressure level (LAeq) above the noise rating limit of 85 dBA. Machines measured in campus A had the highest area noise levels (LAeq) with mean noise levels of 98.8 dBA ±6.9, followed by campus B and C with mean noise levels of 92.9 dBA ±8.3 and 91.6 dBA ±5.1 respectively. The overall statistical difference in the mean area noise levels (LAeq) between the three campuses were found to be not significant (P = 0.135).

The findings of this study demonstrated that the study participants comprised a total of 18 males across the 3 campuses, with mean working experience in the current job of five (5) years (ranging 2 – 11 years). Majority (9 out of 18 or 50%) of the participants were aged between 36–45, while only 16% (3 out of 18) were above the age of 56. The distribution of the participants according to their education was 100% secondary school. This may have positive implications for understanding of information and training material used for noise exposure awareness.

The results of groundskeepers' awareness to certain elements of hearing conservation program, with specific focus to information and training, audiometric testing, and use of hearing protection devices (HPDs) revealed that majority (95%) of groundskeepers were not trained about the noise rating limit and its meaning as required by Regulation 4 of the NIHL Regulations. Furthermore, it was found that, 50% of groundskeepers indicated that they never received information and training on the health effects of noise exposure while working at the university. In terms of audiometric testing, 78% of groundskeepers indicated that they were given audiometric testing while employed at the university. The study further indicated that majority (63%) of groundskeepers reported that, they use hearing protection devices (HPDs) while operating noisy machines. Notably, 90% of groundskeepers reported that, there is no one who is checking and supervising if they wore HPDs while operating lawn maintenance machines. The analysis further shows that, 47% of groundskeepers reported that, their HDPs were not comfortable when worn.

Conclusion

The findings of this study have highlighted that, although the university had hearing conservation programs in place, there were shortcomings in the implementation of some elements of the program, in particular with regard to information and training, noise exposure monitoring and use of hearing protection devices. Most groundskeepers were exposed to noise levels exceeding the noise rating limit of 85 dBA and were at risk of acquiring NIHL. When considering the peak noise levels, the results of the study showed that there was only one groundskeeper from campus A who was exposed to noise levels exceeding the peak limit of 140 dBC. In all cases, employees should never be exposed to peak noise levels in excess of 140 dBC. Prevention, by reducing the noise exposure via engineering measures should be prioritized. The peak noise exposure limit of 140 dBC is regulated in the European Union Physical Agents (noise) Directive 2003/10/EC (2003) as an upper exposure action value. This EU noise directive is adopted by most European countries. Currently in the South African NIHL Regulations and SANS 10083 standard, peak noise exposure levels are not regulated.

No significant differences were found in the mean area and personal noise levels measured in the three campuses. However, the use of certain machines such as backpack leaf blower and chainsaw were shown to be associated high noise exposure levels. Therefore, it is essential to ensure that noise levels on the lawn maintanance machines are significantly reduced by implementing good maintenance practices and buy quiet program. Information and training interventions should be aligned to target potentially exposed groundskeepers to modify their perceptions, noise control adherence approaches and continual motivation to sustain and improve an implemented hearing conservation program.

This is the first study in South Africa to evalaute occupational noise exposure among groundskeepers in a public univeristy. Findings from this study may contribute to existing knowledge on occupational noise exposure among groundskeepers and may be investigated by other universities where lawn mainteance machines are used. However, the findings of this study may not be generalized to other universities because the study was only conducted in one university. Lessons drawn from this study are that there is a greater need to enhance hearing conservation measures in gardening and landscaping services within the universities.

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Abbreviations and acronyms

ACGIH	American Conference of Governmental Industrial Hygienists
dB	Decibel
dBA	Decibel measured using A-frequency weighting
dBC	Decibel measured using C-frequency weighting
EU	European Union
HCP	Hearing Conservation Program
HPD	Hearing Protection Devices
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
LAeq, 8h	Eight-hour equivalent continuous A weighted sound pressure level in dB(A)
Leq	Equivalent continuous sound level
LCpeak	The C-weighted peak sound pressure level in decibel
MHSA	Mine Health and Safety Act
NIHL	Noise Induced Hearing Loss
NIOSH	National Institute for Occupational Safety and Health
OEL	Occupational Exposure Limit
OHSA	Occupational Health and Safety Act
OSHA	Occupational Safety and Health Administration
PND	Personal Noise Dosimeter
PTS	Permanent Threshold Shift
RPM	Revolutions per minute
SANAS	South African National Accreditation System
SANS	South African National Standards
SLM	Sound Level Meter
TWA	Time-Weighted Average
TTS	Temporary Threshold Shift
WHO	World Health Organization

Definitions

A-weighted noise level: The noise level in dBA, measured using the filter specified as the A-network. This measure has been widely used to evaluate occupational noise exposure because of its good correlation with human hearing damage.

Decibel: A unit for measuring sound level

Equivalent continuous sound pressure level (Leq): is the steady sound pressure level which, over a given period of time, has the same total energy as the actual fluctuating noise. The A-weighted equivalent sound pressure level is denoted LAeq.

Exchange rate: The change in average noise level (in dB) that corresponds to a doubling or halving of allowable exposure time. For example, a 3 dB exchange rate permits a doubling or halving of exposure duration for every 3 dB increase or decrease in average noise level, respectively. For example, 8 hours of noise exposure permitted at 85 dBA, 4 hours at 88 dBA, 2 hours at 91 dBA, etc

Hearing Conservation Program (HCP): A program designed to prevent hearing loss in the workplace.

LAeq, 8h: Eight-hour equivalent continuous A-weighted sound pressure level on decibel, referenced to 20 micropascals, determined in accordance with SANS 10083 standard. This is related to the total amount of noise energy a person is exposed to in the course of their working day.

LCpeak: The C-weighted peak sound pressure level in decibel, referenced to 20 micropascals. It usually relates to loud, sudden noise such as gunshot or hammering. LCpeak values above 140 dBC can cause immediate damage to hearing.

Noise Induced Hearing Loss (NIHL): Permanent hearing loss caused by exposure to loud noise; characterized by a high frequency hearing loss and tinnitus

Noise: Noise is any unwanted sound that is too loud, could interfere with hearing and communication, may be unpleasant and could damage hearing.

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CHAPTER ONE: INTRODUCTION

This chapter begins with an overview of occupational noise exposure and its sources across different industries and its health effects on employees. Occupational noise exposure among groundskeepers in the university settings is outlined and the chapter further describes the different types of lawn maintenance machinery associated with exposure to noise. The problem statement and justification of the study are outlined and the chapter ends by presenting the study aim, hypothesis, and objectives.

1. Background

Occupational noise exposure is one of the most frequent hazards present in the workplace and depending on the level and duration of exposure, can cause a range of health effects from annoyance, sleep disturbance and noise-induced hearing loss (NIHL). [(1)] Although many other health effects of noise exposure have been reported, NIHL is recognized as the primary health effect of noise exposure, thus making it a significant and growing health concern with economic consequences.[(2)] In 2018, the World Health Organization (WHO) reported that about 16% - 24% of the disabling hearing loss in adults is attributable to occupational noise exposure, with developing countries such as South Africa carrying the highest risks.[(3)] It was further estimated by the WHO that NIHL costs approximately 0,2% to 2% of the Gross Domestic Product (GDP) of developed nations. In the United States of America (USA), for example, approximately 30 million workers are exposed to hazardous noise at work each year, increasing the risk of noise-related health effects.[(4)] Studies have indicated that workers employed in manufacturing, transportation, construction, mining, utility, agriculture and military have the highest risk of NIHL.[(5, 6)]

Noise, which is essentially defined as any unwanted or undesirable sound, is not a new hazard. For at least 100 years, it has been known that excessive exposure to noise can cause permanent hearing loss.[(7)] From the acoustics point of view, sound and noise constitute the same phenomenon of atmospheric pressure fluctuations and their differences are greatly subjective. Sound, which is what we hear, is technically described as propagated fluctuations in atmospheric pressure capable of causing the sensation of hearing.[(8)]

Prolonged or repeated exposure to excessive noise can cause auditory effects such as permanent hearing loss, known as noise-induced hearing loss (NIHL), tinnitus (ringing in the ear) and other non-auditory effects such annoyance, speech interference, sleep disturbance, fatigue, reduce performance, hypertension and cardiovascular diseases.[1, 9, 10] Fortunately, NIHL is 100% preventable, however, once acquired it is permanent and irreversible.[11] These health effects can limit worker's ability to communicate and hear warning signals, which may have effect on their safety and productivity.

Research demonstrates that continuous exposure to noise levels at or above the 8-hour time-weighted average (TWA) of 85 decibel A-weighted (dBA) may cause permanent hearing loss.[5] Acute hearing loss can also occur suddenly if a person is exposed to very high impact noise for a short duration such as explosion and gun shots. These type of noise can cause instantaneous damage to the ear, often called acoustic trauma.[12]

For worker protection against NIHL, many countries around the world such as the United States, United Kingdom (UK), European Union (EU,) Australia, including South Africa, have implemented occupational noise legislations.[13] Majority of these countries use 85 dBA as the legislated limit for occupational noise exposure and a 3-dB exchange rate in with the exception of the United States which use 90 dBA and 5-dB exchange rate.[14-16] Other prominent international agencies such as the U.S Environmental Protection Agency (EPA), National Institute for Occupational Safety and Health (NIOSH), International Institute of Noise Control Engineering (I-INCE) and American Conference of Governmental Industrial Hygienists (ACGIH) also adopted a 85 dBA as the recommended exposure limit.[7]

In South Africa, employee exposure to noise is governed by Noise-Induced Hearing Loss Regulations (NIHLR) under the Occupational Health and Safety Act (85 of 1993). In terms of NIHLR, no employer shall permit an employee to work in an environment in which he/she is exposed to an equivalent noise level equal to or above 85 dBA.[14]

The noise exposure limit of 85 dBA is not designed to protect all workers from hearing loss as exposure to 85 dBA may still result in an 8% excess of developing hearing loss, during a 40-year lifetime.[11] This noise exposure limit (85 dBA) represent conditions under which it is believed that nearly all workers may be repeatedly exposed without adverse effects on their ability to hear and understand normal speech.[17] Occupational noise is measured in a logarithmic decibel (dB) scale, which is usually expressed in the "A-weighted" response, denoted as dB(A). The A-weighted response simulates the sensitivity of the human ear at moderate sound levels. For this reason, A-weighted sound levels provide a good correlation for noise exposure and the potential loss of hearing from chronic noise exposure, that is why is used in many occupational noise exposure regulations and standards.[18]

Exposure to excessive noise is a global problem, covering a wide range of industry sectors and occupations such as mining, construction, agriculture and manufacturing, including landscaping and gardening services sector.[5] Although regulations and standards are in place such as Noise Induced Hearing Loss Regulations in South Africa to control noise exposure, many workers continue to be exposed to excessive noise levels, placing groundskeepers at risk for the development of NIHL.[10]

For the purpose of this study, lawn maintenance machines will be referred to as machines and groundskeepers as machine operators. These activities may expose the workers to a variety of health hazards such as excessive noise, vibration, thermal stress, dust and exhaust emissions (e.g. carbon monoxide).[19] Noise exposure, which is one of the main health hazards that severely affect the health of these workers during operation of gasoline-powered noise-producing machines such as leaf blowers, riding and push lawnmowers, brush-cutters and chainsaws can be a significant source of workplace noise exposure among the operators.[19, 20]

The landscaping or grounds maintenance activities in university campuses are rapidly growing around the world due to great demand in maintaining neatness and keeping the beauty nature of landscapes in these facilities, which means that more workers are potentially exposed to noise levels when operating powered machines.[21] Studies conducted in the landscaping sector around the world, with the focus on universities, have shown that lawn maintenance machines produce noise levels well in excess of 85 dBA. The noise produced by these machines are of various sources, i.e. from the motor, exhaust, fan, and from the blades/ or plastic string that breaks out the grass. For instance, typical noise level of a lawnmower is 90 dBA, a leaf blower is 111 dBA and a brush-cutter is 105 dBA.[20-22]

For at least 100 years, it has been known that excessive exposure to noise, depending on the level and duration of exposure, can result in permanent hearing loss.[23] Since then, most studies were carried out on occupational noise exposure and focused mainly on formal industrial sectors such as mining, construction, agriculture, utilities, military, manufacturing and transportation.[24, 25] For instance, activities in the mining sector such as rock drilling, blasting and crushing of ore are listed as some of the major noise generating activities.[26] In other industrial sectors, noise-generating activities vary, depending on the task.[27]

Although the literature on occupational noise exposure has concentrated on large industrial sectors (mining, construction, manufacturing and transportation), the problem extends to smaller operations such as lawn maintenance. Recent literature suggests that noise generating activities in small-scale operations, such as lawn maintenance, use high noise emitting machinery.(22, 25) Research studies on noise exposure among groundkeepers are limited and no current published research studies were found in South Africa.

Until recently, noise exposure levels among groundskeepers who operate various noisy machines were not well characterized and current evaluation is needed to fill the gap in the literature.(28)

1.1 Problem statement

Groundskeepers who are employed in most public universities operate a variety of noisy gasoline-powered machines to maintain the grounds on a daily basis.(29)These groundskeepers are constantly subjected to noise levels above 85 dBA emitted from these equipment while on the job, thus putting them at risk of acquiring NIHL.(21, 29) Most of these workers are exposed to noise levels 8-10 hours per day exposed to excessive noise levels and only few of them wear hearing protective devices (HPDs).(30)

It is evident from the literature (1, 31) that noise is a problem in large industries such as mining, manufacturing and construction, and these industries have been extensively studied and listed as having extreme noise exposures. However, noise can also be an issue in other workplaces such as landscaping and grounds maintenance and there is limited information on noise exposure among groundskeepers, both in South Africa and in other countries around the world.(28) Recent global studies that were conducted in the landscaping sector focused mainly on noise levels from similar types/models of machines such as leaf blowers, with less attention on noise levels emitted by a variety of machines used by groundskeepers in university campuses.(32, 33)

According to the researcher’s knowledge, in South Africa, there is currently no available research findings relating to groundskeepers’ noise exposure in public universities and the noise levels of the machinery used is still unknown. Workplace noise exposure in South Africa is regulated under the Noise Induced Hearing Loss (NIHL) Regulations of the Occupational Health and Safety Act 85 of 1993 and Mine Health and Safety Act (29 of 1996) specific to mining industry. The NIHL Regulations stipulates that, no employer shall permit any person to enter any workplace under his or her control where such person will be exposed to noise at or above the 85 dBA noise-rating limit.[14] The NIHL Regulations further makes reference to a hearing conservation program (HCP) that aims at controlling exposure to noise. Some of the elements of the HCP, as contained in the SANS 10083 standard, include noise monitoring to assess the degree of hazardous noise exposure, engineering controls, audiometric testing, information and training and provision of hearing protective devices to reduce the noise reaching the ears.[34]

1.2 Justification for the study

Presently, it is suggested that groundskeepers are among the most noise exposed group of workers due to the nature of their work.[21] According to the NIOSH, landscaping industry is one of the hazardous industries in the services sector.[35] Despite the availability of legislative frameworks, knowledge and solutions that deals with noise exposure, noise levels in excess of 85 dBA are still being report in most occupational settings around the world, including South Africa.[3, 26] The South African Occupational Health and Safety Act 85 of 1993 (OHSA) requires the employer to bring about and maintain, as far as reasonably practicable, a work environment that is safe and without risk to the health of the workers.[36] The Noise-Induced Hearing Loss (NIHL) Regulations further states that no employer shall require or permit any person to enter any workplace where such person will be exposed to noise at or above the 85 dBA noise-rating limit.

The university employs full-time groundskeepers who operate different types of powered lawn maintenance machines frequently.[37] Therefore, conducting this study is important and it will provide the necessary baseline data on occupational noise exposure among groundskeepers and estimate their risk for NIHL and provide better understanding and suggestions for improving the current hearing conservation practices.

This study will also be beneficial to the University management and groundskeepers as it will advance knowledge on noise levels emitted by the different types of lawn maintenance machines and help to identify and manage the risk of machinery emitting high noise levels (e.g. “by implementing a “Buy Quite” initiative). Furthermore, the findings of the study may form a basis for policy formulation and implementation to better allocate resources to enhance proper occupational health and safety governance such as hearing conservation program.

The lack of existing database for lawn maintenance machines noise levels suggest the need to further explore or investigate these sources of noise to determine their inherent risk to workers. This study may provide baseline data for the development of hearing conservation program and additional information to further understand the extent of noise exposure among groundskeepers. Such data may be useful in the establishment of the noise sources inventory, used in health studies and better inform epidemiological studies because exposure to excessive noise is an important aspect of public health and constitutes a health risk.[9]

1.3 Hypothesis

The study hypotheses that groundskeepers who operate gasoline-powered lawn maintenance machines are exposed to time-weighted average noise levels at or above 85 dBA. The study also hypotheses that the different types of lawn maintenance machines emit different noise levels depending on the make and model of the machine.

1.4 Study aim

The aim of this study was to evaluate noise exposure levels of groundskeepers who operate different types of powered lawn maintenance machines at the three campuses of a public university in Gauteng and estimate their risk of NIHL.

1.5 Study objectives

1. To describe the groundskeepers' basic demographic characteristics, work activities and work environment conditions at the three campuses of a public university in Gauteng;
2. To describe the specifications of the different types of lawn maintenance machines operated by groundskeepers at the three campuses of a public university in Gauteng;
3. To characterize source (machinery) noise levels of different lawn maintenance machines and compare their equivalent continuous sound levels (LAeq);
4. To assess the groundskeepers' personal noise exposure levels while operating the lawn maintenance machines at the different campuses and compare their noise exposure levels to the regulated 8-hour TWA noise rating limit of 85 dBA;
5. To determine whether groundskeepers have increased risk of NIHL based on the measured noise levels and existing controls.

CHAPTER TWO: LITERATURE REVIEW

This chapter focuses on reviewing the existing literature related to noise exposure in order to establish the link between this study and what has already been studied. This chapter begins with describing the physical properties of noise such as amplitude, speed, frequency and duration which are important characteristics of noise exposure. A description of occupational noise is outlined in this chapter since this type of noise have impact on human health. Noise exposure and sources of noise emissions in the landscaping sector is also outlined in this chapter. It further discusses health effects associated with noise exposure, legislation on noise exposure and ending with the discussion of exposure controls related to noise focusing on hierarchy of control.

2. LITERATURE REVIEW

2.1 Physical properties of sound

Sound usually consists of many tones of different properties and atmospheric pressure variations such as amplitude, frequency, wavelength and velocity. Sound is a form of energy and can be formally defined as the fluctuations in pressure above and below the ambient pressure of a medium that has elasticity and viscosity.(23) The speed at which sound propagates is a function of the mediums elasticity and density. For example, at 21 degrees Celsius, the speed of sound in air is 344 metres per second (m/s). In other medium such as solids and liquids, sounds travel faster due to higher ratio of elasticity to density, that is to say, about 1500 m/s.(11)

The frequency (Hz), wavelength (m), and speed of sound (m/s) are related. The wavelength of sound is important in designing noise control measures because sound absorptive controls should be at least one quarter wavelength thick for optimum absorption.(7) The rapidity of pressure fluctuations at the human ear which cause the sensation of sound is expressed as the frequency of sound. Sound frequency is perceived as pitch (e.g. how high or low a tone is). The range of frequency which are audible to the human ear extends from about 20 Hz to 20 000 Hz, but varies from person to person and also depends upon age. As a person gets older, the highest frequency that he or she can detect tends to decrease.(38, 39)

The dynamic range of hearing sensitivity is large, beginning with a very weak pressure causing faint sounds and increasing to noise so loud that it causes pain. As a result of this very large dynamic range, sound is often described in terms of a logarithmic quantity, sound pressure level[11]. Noise is measured in decibel which is the unit used to measure the intensity of sound. The decibel unit may give numbers that do not relate well to the subjective impression of the noise heard by humans. To overcome this problem, the sensitivity of the human ear to sound depends on the frequency or pitch of the sound, therefore, noise measurement readings can be adjusted to correspond to human hearing sensitivity by applying A-weighting filter which is built into the mostly common used noise measuring instruments such a sound level meter and personal noise dosimeter. Because A-weighting is mostly used to resemble the. sensitivity of the hu man ear, most international standards for noise use this scale, abbreviated as dBA[39].

2.2 Occupational noise exposure in mining industry

The Mine Health and Safety Act 29 of 1996 (MHSA) is the principal law regulating occupational health practice in the South African mining industry, including management on occupational noise exposure.[40] Noise exposure is a significant occupational health risk within South African mining industry, due to high noise levels emitted by various equipment within the mining environment. Mining is one of the largest industries in South Africa, employing more than 450 000 people.[41] NIHL continues to be a significant occupational disease in South African mines, accounting for 29% of all diseases in 2019.[42] Mining activities are highly mechanised and generate high noise levels from various equipment such as the use of drilling and rock breaking equipment.

In 2011, a study investigating profiles of noise exposure levels in South African mining, revealed that the mean noise ranged from 64 dBA to 114 dBA. The study also showed that approximately 90% of miners in the industry were exposed to noise levels above the occupational exposure limit (OEL) of 85 dBA.[43] The National Institute for Occupational Safety and Health (NIOSH) in the USA reported that 80% of USA miners work in areas in which noise levels the OEL. Examples of coal miners’ exposure to noise included stagelaoders (ranged: 82 to 103 dBA), hydraulic pump and attendants (ranged: 74 to 103 dBA). Other job categories/work areas impacted by noise exposure included winch operators (ranged: 97 to 98 dBA), and stoppers (ranged: 104 to 112 dBA).

Through the Mine Health and Safety Council (MHSC), the South African mining industry has since 2003, established milestones on the elimination of NIHL. The milestones were that by December 2024, the total operational or process noise emitted by any equipment must not exceed noise level of 107 dBA. The other focus area of these milestones were strengthened by the introduction of the Mining Occupational Safety and Health (MOSH) system, which focuses on the adoption of leading practices within mining sector such as “buy and maintain quiet” initiative.[44]

2.3 Noise exposure and sources of noise emissions in landscaping sector

In the landscaping and gardening services sector, the extensive use of powered lawn maintenance machines results in widespread exposure to high levels of noise.[28] Landscaping sector is one of the sectors that employs many workers such as groundskeepers who use and operate different types of lawn maintenance machines for maintenance of grass areas and keeping beauty nature of landscapes.[45] These workers, formally called groundskeepers, are in charge of maintaining general landscape of public and private areas such as sporting grounds, community parks and learning institutions grounds. Their main tasks involve a variety of outdoor activities such as clearing leaves, mowing lawns, cutting trees, trimming hedges, applying fertilizer, removing dead or unwanted plants and other general garden maintenance work.[19, 45]

Noise is not a new health hazard and has been observed for centuries.[7] Powered lawn maintenance machines such as riding mowers, brush cutters and leave blowers can pose significant hazards in the workplace, including excessive noise emissions. The source of noise emissions from these machines are mainly characterized by motorized gasoline powered engine, cutting blades and plastic string spinning at high speed.[25] The noise patterns of these machines can vary between fluctuating, intermittent and impulsive. Most reported cases of NIHL are attributed to impulsive or peak noise exposure which produces larger hearing losses when compared to steady state noise.[45] The use of these powered machines can produce noise levels well above the legislated limit of 85 dBA.(28) A comparative cross- sectional study conducted in Malaysia in 2017, focused on seventy-five grass-trimming workers, found that the maximum noise level emitted by the grass-trimming machine was 100.7 dBA, with a mean of 95 dBA.(25) An experimental study conducted by Pasanen et al[20], which examined noise levels of leaf blowers, brush cuter, lawn mowers and snow blowers found that noise exposure of leaf blower users varied between 102 dBA to 111 dBA. Only lawn mowers noise levels were less than 100 dBA.

A recent study by Balanay et al[21] looked at noise exposure among groundskeepers in North Carolina Universities. They measured the noise levels of several common lawn maintenance machines such as riding mowers, chainsaws, leaf blowers and found that many produced noise levels higher than 85 dBA, ranging from 86 dBA to 109 dBA. In 2020, Naskrent et al[46] examined the impact of cutting attachment type on noise levels during tending of young pine stands. The attachments included a wire head and cutting blades fitted on brush cutter machine. They found that the wire head resulted in highest noise emissions of 122 dBA when compared to cutting blades.

Mallick et al carried-out noise investigation on two types of grass-trimming machine engines to determine their noise effect on operators. They found that the noise levels between the two machines ranged from 100 dBA to 105 dBA. They also observed that noise levels were aggravated when a number of machines were simultaneously operated in close proximity to one another.[22]

2.4 Health effects of excessive noise exposure

Exposure to noise constitutes a health risk and there is sufficient evidence that noise exposure can induce permanent hearing loss, hypertension and ischemic disease, interfere with communication, annoyance, sleep disturbance and decrease school performance.[9] In the he workplace, sound is generally transmitted through air and at standard temperature and pressure (STP), it travels at a speed of about 344 meters per second.[39] The sound emitted through the air are collected in the three main auditory components (outer ear, middle ear, inner ear). The inner ear is the most complex and sensitive part of the auditory system and contains thousands of delicate hair cells in the organ of corti which can be damaged by various factors including aging, loud noise and ototoxic chemicals (e.g. solvents).[37]

Excessive noise exposure may at first cause temporary threshold shifts (TTS) in hearing. If exposure to excessive noise levels continues for a longer period, the ear can develop permanent threshold shifts (PTS). For instance, TTS can occur after short duration of exposure to highly impulsive noise (e.g. gun shot or explosion) and may fully recover within 24-48 hours. PTS, which is irreversible, occurs when the hair cells in the cochlea are damaged by chronic exposure to excessive noise levels. TTS in hearing is often accompanied by tinnitus, a ringing sound in the ears, that itself can be temporary or permanent.[2, 37]

A wide variety of chemicals and medication may, alone or in concert with noise, result in hearing loss. These substances are called ototoxic substances. Some examples of industrial ototoxic agents are solvents including toluene, styrene, trichloroethylene, carbon disulphide, hexane and butanol, and toxic metals including lead, mercury and trimethyltin. Ototoxic substances absorbed into the bloodstream may damage the cochlea in the inner ear and/or the auditory pathways to the brain, leading to hearing loss and tinnitus. Hearing loss is more likely if exposure is to a combination of substances or a combination of the substance and noise.[11, 37]

2.5 Noise exposure legislation

There are a variety of occupational noise exposure limits in use around the world.[13] One of the commonly accepted and used standard is International Organization for Standardization (ISO) 1999:1990.[26] Millions of workers around the world are exposed to hazardous noise levels in their respective workplaces and the need for legislation to adequately protect the hearing of workers is of utmost importance.[1] The WHO has reported that occupational noise exposure is responsible for 16% of cases of hearing loss in adults. Legislation relating to occupational noise exposure has been adopted in many countries around the world with prominent differences in exposure limit and exchange rate. The NIOSH defines exchange rate as an increment of decibels that requires the halving of exposure time, or a decrement of decibels that requires the doubling of exposure time. For example, a 3-dB exchange rate requires noise exposure time to be halved for each 3 dB increase in noise level, similarly, a dB exchange rate requires exposure time be halved for 5 dB increase. A number of studies support a 3-dB exchange rate, except OSHA in the U.S which uses 5 dB exchange rate.[11]

One of the commonly applied standards with regard to noise occupational noise exposure is the International Organization for Standardization (ISO) 1999:1990 which stipulates an exposure level of 85 dBA. This standard can be used to predict the severity of NIHL of the exposed population, taking into account exposure level and duration, age and sex. The European Union Directive 2003/10/EC specifies three limits for noise exposure, namely, lower exposure action value of 80 dBA, an upper exposure action value of 85 dBA and exposure limit of 87 dBA.[47] In the South African context, the standard-setting agency on the noise exposure legislative requirements is South African National Standard (SANS) 10083:2021.[34] This standard stipulates an 8-hour TWA noise-rating limit of 85 dBA. The statutory requirements with respect to occupational noise exposure in South African are specified in the Department of Employment and Labour Noise-Induced Hearing Loss Regulations, promulgated under the Occupational Health and Safety Act 85 of 1993.[14] The NIHL Regulations states that the noise- rating limit of 85 dBA should not be exceeded and requires the employer to implement hearing conservation program (HCP) when workers are exposed to noise levels at or above this limit. Current scientific knowledge has shown that noise levels of less than 75 dBA are unlikely to cause NIHL, while noise levels above 85 dBA with exposure of 8-hour time-weighted average (TWA) per day can produce NIHL.[2] Research conducted by the United States (U.S) based National Institute for Occupational Safety and Health (NIOSH) in 1998 showed that there was an 8% excess risk of hearing loss at 85 dBA TWA limit over a 40-year working lifetime. The risk of NIHL depends on the frequency distribution, level and duration of the noise as well as individual susceptibility such as age and gender. [11]

CHAPTER THREE: METHODOLOGY

This chapter provides a layout of the methodology followed for this research. Personal and area noise measurements data was collected from the lawn maintenance machines and from the groundskeepers who operated these machines, following a convenience sampling strategy. Noise measurements (both area and personal) were collected at the three university campuses, namely campus A, B and C, using an integrating sound level meter and personal noise dosimeters. Noise measurement results were compared with noise rating limit of 85 dBA in order to determine the risk of noise induced hearing loss among groundskeepers and also to identify machines that emitted excessive noise levels. Quality control measures were strictly observed during data collection. This chapter concludes with the ethical consideration of the study.

3. Study design

This was a quantitative, cross-sectional study design conducted among groundskeepers following a convenience sampling strategy. This study design was best suited in terms of examining the prevalence of occupational noise exposure among groundskeepers at a certain point in time, without attempting to change or modify their situation.[48]

3.1 Study site

3.2.1 Description of the study settings

This study was conducted at the three campuses of a public university located in the City of Johannesburg (CoJ), Gauteng Province. According to the university's Facts and Figures report released in 2021, the university is spread over 162 hectares, has 11 libraries, about 40 000 student enrolments, 1000 full-time permanent employees and 18 residence accommodating 20% of the student population. The university also has over 30 service departments, including Grounds Services Department, where this study was conducted.[49] The lawn maintenance activities were managed under the Grounds Services Department which was divided into Landscaping, Turf (sports fields) and Waste Management Divisions.

There were five possible campuses in total to choose from as part of this study. However due to limited availability of resources, the primary researcher conveniently chose the three campuses out of the five based on their large land sizes, frequency of lawn maintenance tasks, availability and use of different types of lawn maintenance machines and having the potential for noise exposure for the entire shift duration of the data collection. The other two campuses were excluded from the study due to limited use of lawn maintenance machines. For the purpose of this research report, the campuses were the study was conducted are labelled as Campus A, Campus B and Campus C.

Another consideration for choosing the three campuses was based on practical reasons as the researcher stays in close proximity to the university and the support offered by the university management to conduct this study. Owing to limited time, budget and resource constraints, the study was confined to only three campuses.

3.2 Study population

The study population included all full-time lawn maintenance workers of the Grounds Services Department. According to the information obtained from the university Grounds Services Department Manager and the records provided during the walkthrough, there were approximately ninety-six (N=96) employees working under the three campuses, including general workers, machine operators/groundskeepers, drivers, supervisors/managers, and operations administrators. The general duties of groundskeepers included a variety of outdoor activities such as clearing leaves, mowing lawns, cutting trees, trimming hedges, applying fertilizer, removing dead or unwanted plants, planting trees and other general garden maintenance work. They also ensure outdoor areas within the university are safe, functional and appealing.

3.3 Study sample and sample size

There were 22 machine operators working at the three campuses. Prior to the final field survey, a pilot study was conducted with one groundskeeper to test the data sampling tool (questionnaire) and the instruments (SLM and PND). The remaining 21 groundskeepers, excluding the one who participated during the pilot survey, were invited to participate in the final study.

The inclusion criteria for the study sample frame included all groundskeepers who operated lawn maintenance machines at the three university campuses and the consideration of rainy season which represented worse-case scenario for noise exposure during lawn maintenance activities. The months of September and November were specifically chosen for data collection because they fall under rainy season in the South African context. Abundant rainfall was anticipated during these months, which resulted in grass growing faster when compared to dry season and ultimately increasing the duration and frequency of lawn maintenance activities. Exclusion criteria included workers who did not operate lawn maintenance machines such as general workers, managers and the machine operator that participated on pilot study

Due to a relatively small number of available study participants, a sample size of 18 groundskeepers was conveniently selected to participate in the study. These groundskeepers were selected on the basis of operating noisy machines and, therefore, expected to have higher noise exposures. A convenience sample was chosen on the basis of machine operators' availability at a given time, willingness to participate in the study and easy accessibility. This study comprised of two categories of measurements, namely, personal (task-based) and area (source/machinery) noise measurements. A total of 18 personal measurements were collected in the three university campuses using personal noise dosimeters. A further total of 17 area noise measurements were also collected in the same university campuses using an integrating sound level meter (SLM). Initially, the primary researcher anticipated to include all 22 groundskeepers to participate in the study, however, only 18 out of 22 were available to participated. Of the 22 participants, 3 did not participate in the study due to unavailability of lawn maintenance tasks allocated to them during noise measurements. The exclusion of the 3 nonparticipating groundskeepers was approved by the research study supervisors.

Supervisors from each campus assisted the primary researcher with identifying groundskeepers with duties exclusive to operating lawn maintenance machines.

3.4 Data collection tool

3.4.1 *Pilot study*

A pilot study was conducted by the primary researcher at Campus A prior to collection of actual data. The purpose of the pilot study was to pre-test the feasibility of the study and identify potential problem areas and deficiencies in the data collection tools prior to commencement of the actual study. The pilot study was also conducted to assess whether the study participants easily understood the questions and content covered in the interview guide/field data sheet.

The pilot study was also used to identify all groundskeepers likely to be exposed to noise, obtain information on noise sources and work practices, and existing noise control measures or lack thereof. Data collection tools that were tested as part of the pilot study included field data sheet, questionnaire, noise measuring instruments (sound level meter and personal noise dosimeter) and environmental conditions monitoring instruments (TSI VelociCalc hotwire-anemometer and Q-Trak).

One participant from Campus A was selected to participate in the pilot study. The results of the pilot study revealed that the participant understood the questions contained in the interview guide and field data sheet. The feedback provided by the participant enabled the researcher to easily follow and complete the questionnaires in full. Noise measuring instruments were also pre-tested by the researcher. The sound level meter and personal noise dosimeter were calibrated before and after each measurement session to ensure that the instruments were functioning properly and provided accurate results as per the SANS 10083 standard and manufactures specifications. The measurement sessions were simulated for a short duration in order to allow for pre and post calibration.

The results of pre-test noise measurements showed that the instruments performed in accordance with the manufactures specifications and produced satisfactory results which were in line with the aim of the study. As the participant in the pilot study was from one of the campuses used for the main study, his results were not used in the main study. In view of only one study participant that was used to pilot the tool, two Occupational Hygiene Specialists were also invited to review the tool in order to increase validity and reliability. The results of the validity and reliability of the questionnaires by two Occupational Hygiene Specialists revealed that the questionnaires were easy to follow in terms of its language, format and layout, sequence of questions, instruction, clarity of sentences, number of items and relevance of the contents to the topic.

3.4.2 *Questionnaire*

A questionnaire constructed by the primary researcher was utilized to record demographic information about the study participants and their work processes pertaining to tasks they performed and noise exposure (Appendix E and F). Prior to any engagement and administering the questionnaires with research participants, ethical approval was sought from the Human Research Ethics Committee of the University of the Witwatersrand in Johannesburg. The ethics approval number for this study was M210242 MED21-01-104. The primary researcher conducted an information session with the study participants who were gathered together at Campus A and explained the following aspects to the participants: aim of the study, what is expected from the participants, the informed consent form and confidentiality, the operating principles of the noise measuring instruments (sound level meter and noise dosimeter) and the length of the data collection and the possibility of the research findings being published. For example, with regard to measurement of personal noise using a dosimeter, the primary researcher explained to the participants that the dosimeter only records noise levels and that it does not record speech. All participants were given the opportunity to ask any questions relating to the study and were asked to sign informed consent forms (Appendix D).

The data collection tools consisted of two parts, namely field data sheet and questionnaire. The field data sheet was used to record the following technical information: environmental conditions, lawn maintenance machine’s specifications, sound level meter and personal noise dosimeter information, including calibration data and description of the measured areas. The demographic information with variables such as age, sex, job title, level of education, home language, ethnicity, years in current job and noise exposure awareness were assessed using questionnaire. The aspects of noise exposure awareness included information and training, audiometric testing, and hearing protective devices (HPDs). This information enabled the researcher to thoroughly describe the study participants and evaluate certain elements of the hearing conservation program employed at the university.

A structured interviewer-administered questionnaire was used to assess groundskeepers’ awareness to aspects of noise exposure, with specific focus to information and training, audiometric testing, and hearing protection devices (HPDs). This information enabled the researcher to thoroughly describe the study participants and evaluate certain elements of the hearing conservation program employed at the university.

3.4.3 *Lawn maintenance machines characteristics*

Information about the different types of machines used at the three campuses was requested by the researcher during data collection and recorded on the field data sheet. An inventory of all machines, including their operator manuals was provided to the primary researcher. The inventory was requested to identify all machines that were used and available for noise measurements in different campuses. Operator manuals of the machines were also requested in order to capture technical information such as engine speed, sound power level and sound pressure level. Upon studying the equipment inventory, the researcher discovered that not all machines had operator manuals onsite. For those machines that did not have operator manuals, the researcher acquired their specifications from the respective machinery manufacturers’ websites. When searching the websites, it was discovered that only the operator manuals for the latest models of the machines were kept on the website and the specifications of some of the older models could not be found. Hence technical specifications of other machines could not be captured in this study.

A total of 23 machines operated by the groundskeepers in the three selected campuses were assessed and their specification recorded on the field data sheets. The machines used were classified into different categories, namely hand-held, ride-on and push mowers.

3.4.4 *Environmental conditions*

Noise measuring instruments such personal noise dosimeter and integrating sound level meter, including microphones, are very sensitive to environmental factors such wind speed, relative humidity and ambient temperature.[7] In order to account for these environmental factors which may affect the performance and accuracy of the noise measuring instruments, the wind speed was measured (in meters per second) onsite using a hand-held TSI VelociCalc hotwire-anemometer (model 9555-P, Shoreview, Minnesota, USA). The other two parameters, namely relative humidity (in percentage) and ambient temperature (in degrees Celsius) were also measured onsite using a hand-held TSI Q-Trak monitor (model 7575-X, Shoreview, Minnesota, USA). These instruments were externally calibrated by the SANAS ISO/IEC 17025 accredited laboratories.

The three measurement parameters (wind speed, relative humidity, and ambient temperature) were taken each day before and after noise measurements were taken in order to verify whether environmental conditions were conducive for the noise measuring instruments. Prior taking the actual measurements, the primary researcher ensured that the Q-Trak and hotwire anemometer instruments were operated as per their respective manufactures' specifications. The Q-Trak and hotwire anemometer instruments were set to automatically log the readings on an averaging period of 60 seconds. A field data sheet was used to manually record the measured parameters as displayed on the instruments and observations made. The instruments user manuals were followed when taking the measurements.

According to the Casella noise dosimeter user manual[50], the instrument is designed to operate accurately under the following conditions: temperature (0°C to +40°C) and relative humidity (30% to 90%). The Quest integrating sound level meter is designed to operate accurately over the temperature of -10°C to +50°C and relative humidity of 30% to 90%.[51] Wind blowing across the microphone produces spurious readings which may cause an overestimate error in the measurements and to control that, literature showed that noise measurements should be avoided when wind speeds exceed 5 m/s.[38]

3.4.5 *Task-based personal noise exposure monitoring procedure*

Personal (task-based) noise exposure measurements were conducted as per the monitoring strategy and in accordance with the South African National Standard (SANS) Code of Practice 10083:2013 "The measurement and assessment of occupational noise for hearing conservation purposes".[34] Exposure to personal noise were quantified using a calibrated class 2 Casella dBadge noise dosimeter (*CEL-35X, Regent House, Bedford, U.K*) that complies at least with the accuracy requirements specified in SANS 61672-1.[34] In terms of accuracy requirements, a class 2 personal noise dosimeter is suitable for general noise surveys and personal noise exposure monitoring.[52]

The noise dosimeters used complied with the accuracy requirements specified for a types 2 instrument in SANS 61672-1 and International Electrotechnical Commission (IEC) 61252.

Task-based personal noise exposure monitoring methods were chosen for this study based on the information collected during the pilot study. During the pilot study, it was found that groundskeepers rarely operate the machines for the entire 8-hour shift, due to intermittent or varying nature of the lawn maintenance activities, hence task-based methods were adopted. Task-based methods have distinct advantages over full-shift in that they provide a more direct understanding of the specific tasks with high noise exposures, especially considering the changing work environment, high variability in tasks and varying working hours and therefore help target effective noise control strategies.[53]

A personal noise dosimeter (PND) is a small, lightweight and portable data-logging instrument. The instrument can be easily carried around by employees and is preferred for measuring noise exposure of machine operators since they did not have a fixed location and move around frequently from one place to another during the measurement period, which exposed them to intermittent or varying noise levels.[7] The use of PND has the advantage that the measurement comprises the full noise history of the day, including the various tasks and breaks. The dosimeter stores the noise levels during an exposure period and automatically computes the measured noise in equivalent continuous A-weighted sound pressure level (LAeq) and 8-hour TWA (LAeq,8h) that can be readout from the instrument. Figure 1 illustrates a PND mounted on an employee's top middle of the shoulder, approximately 10 cm from the ear that received higher noise levels.

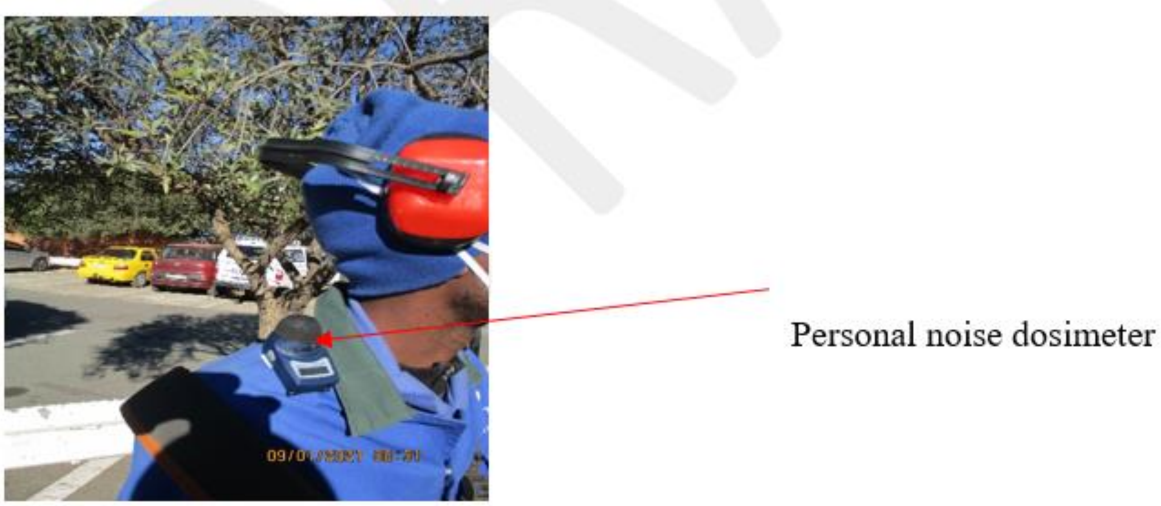


Figure 1: PND mounted on an employee hearing zone (source: photo taken by the researcher)

A total of 18 PND measurements were conveniently collected from the groundskeepers who operated lawn maintenance machines at the three university campuses. Out of the 18 PND measurements, 6 were measured at Campus A, 5 at Campus B and 7 at Campus C. Prior to taking of the measurements, all participants were encouraged to continue working in a routine manner. Instructions were also given to the participants that they should not remove the dosimeter during the measurement session and avoid covering the microphone with their clothing or move the microphone from its installed position as this may affect the noise readings.

To ensure accuracy of measurements, each PND was calibrated before and after each series of sound level measurement as per the manufacturer's instructions using a calibrated type 2 portable acoustic calibrator (*Casella CEL 110/2, Regent House, Bedford, U.K*). The pre and post calibration was performed to ensure that the two-calibration checks do coincide to within 1.0 dB. According to the SANS Code of Practice 10083: 2013, if the two checks do not coincide to within 1.0 dB, the measurements should be discarded. All the PNDs and a sound calibrator were externally calibrated by a South African National Accreditation System (SANAS) 17025 accredited laboratory.

The following noise parameters and settings for PND were applied in determining personal noise exposure as per the SANS 10083 standard: 3-dB energy exchange rate, 85 dBA criterion level, A-weighted equivalent continuous sound pressure level (LAeq), C-weighted peak sound pressure level ($L_C$peak) and zero threshold level.

Groundskeepers were grouped according to three university campuses: Campus A, B and C. From each campus, groundskeepers were issued with PND, by switching them on and noting start time on the field sheet. Groundskeepers were monitored for personal noise exposure throughout the measurement period by wearing PND within the hearing zone (10 cm from the ear with the microphone approximately 4 cm above the shoulder) in order integrate the instantaneous sound exposures and estimate their cumulative noise exposure while operating the machines. The measurements were taken over a sufficiently long-time to be representative of the employees' exposure.

Field observations and worker interviews were made during the measurement period to observe and gather relevant information on groundskeepers work activities, noise sources and existing noise control measures. This information, together with the data from the noise dosimeters, were used to produce estimates of the daily personal noise exposure of the 18 selected groundskeepers.

After the measurements were completed, the PND were removed from the groundskeepers by switching it off and noting the stop time. Information such as dosimeter serial number, total run time, LAeq, peak noise level, primary and secondary noise sources, tasks performed and control measures in place or lack thereof, were recorded on the field-data sheet. The dosimeter stored the noise levels during the exposure period and automatically computes the measured noise in equivalent continuous A-weighted sound pressure level (LAeq) that can be readout from the instrument.[12]

The collected data on the dosimeter was downloaded via its infra-red port onto a computer using a Casella insight data management software. These will allow comprehensive analysis of employee's exposure profile throughout the measurement duration.

To quantify the risk of groundskeepers' daily noise exposure, equation 1 was applied:

$$L_{Aeq,8h} = L_{Aeq,Ts} + 10 \log T_s / 8 \quad (1)$$

Where:

LAeq, 8h	is the equivalent continuous 8-hours rating level
LAeq, Ts	the equivalent continuous rating level, determined over the duration of the working shift.
Ts	is the effective duration of the working day, in hours
8	is the total duration of the reference time interval, in hours

3.4.6 *Estimation of noise-induced hearing loss risk*

Management of occupational noise exposure relies on risk control, which is underpinned by the process of risk assessment (Figure 2). To evaluate the health hazard and determine the risk level derived from noise, the noise exposure levels should be normalized to a nominal 8-hour working day. The connections between the risk levels due to noise and stages of health effects was determined using the simple/ flexible risk assessment method adopted from Reinhold and Tint.[54] This method is based on a five-step simple/ flexible risk matrix, which include different risk levels, namely, tolerable, justified, unjustified, inadmissible and intolerable.

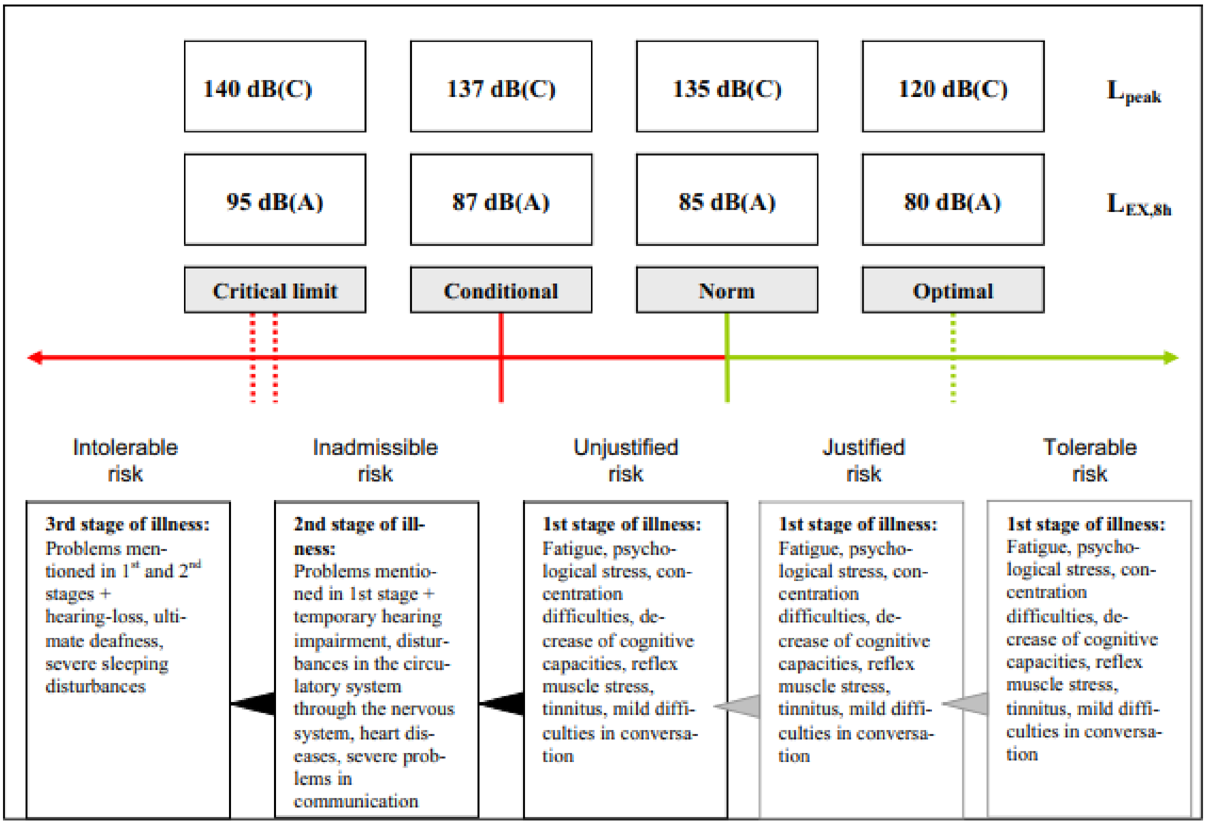


Figure 2: Five-step simple/ flexible risk assessment method (adopted from Reinhold and Tint)

3.4.7 *Area noise monitoring procedure*

Area noise measurements were conducted in accordance with the SANS Code of Practice 10083:2013. In order to quantify noise levels emitted by the lawn maintenance machines, area noise measurements were taken using a calibrated type 1 Quest integrating sound level meter (Model 1900, Quest Technologies, Oconomowoc, USA), fitted with a condenser microphone. A type 1 sound level meter (SLM) is preferred for field use where accurate measurements are required, particularly for noise readings used to help design noise engineering controls.(7). The SLM used complies with the accuracy requirements specified by IEC/SANS 61672-1.(55) To account for potential errors caused by wind blowing across the microphone, a windshield of a type specified by the manufacturer was used to cover the microphone in order to protect against dust, strong wind and physical damages since the measurements were taken outdoors.

The SLM used to collect area noise measurements was programmed using the following parameters/ settings: 85 dBA criterion level, 3-dB exchange rate, impulsive response, no threshold, A-weighted equivalent continuous sound pressure level (LAeq), and A-weighted minimum/maximum sound pressure level ($LAeq_{min/max}$).

A calibrated type 1 acoustic calibrator (Model QC-10, Quest Technologies, USA) was used to calibrate the SLM immediately before and after each series of measurements to ensure measurement accuracy as indicated by the instrument manufacturer's instructions. The pre and post calibration was performed to ensure that the two-calibration checks do coincide to within 1.0 dB. If the two checks do not coincide to within 1.0 dB, the measurements should be discarded. The SLM and a sound calibrator were externally calibrated a SANAS 17025 accredited laboratory.

Before taking the actual source measurements, background (ambient) noise levels were taken using a SLM in order to evaluate the contribution of noise from external sources such as traffic noise. Background noise can cause considerable error in measurement when its level is close to that of noise source of interest.(34) The procedure for accounting for background noise was as follows: (a) the total noise level (ambient plus source) was measured with the machine running, (b) background noise level was measured with the machine turned-off. The difference between the two readings (ambient and machine noise level) was determined using the formula stipulated under SANS Code of Practice 10083:2013.(34) The difference between the two readings should preferably be at least 10 dB higher in order not to apply any corrections to the readings. No corrections were applied to the measurements since the difference between the readings were greater than 10 dB.

A total of 17 different types of machines were measured at the three campuses. Out of the 17 machines, 7 were measured at Campus A, 5 at Campus B and C respectively. A convenience monitoring strategy was employed when selecting the machines. These machines were selected based on the availability of the groundskeepers who were competent to operate the machines and tasks planned on the day of measurements. Due to the varying and intermittent nature of the noise generated by the machines, area noise measurements were chosen in such a way that the variations in the noise levels were adequately covered. Area measurements for each machine were repeated 3-times (one minute per reading) while the machine was operated to sufficiently capture a full cycle of noise variations. A typical full cycle of noise included varying engine speed (idle, full throttle) and the type of grass being cut. A total of 23 machines were assessed across the three campuses.

In order to quantify the area noise measurements, a SLM was mounted on a tripod stand to ensure the microphone was placed as far from the body of the researcher as practicable, to reduce reflective noise. The microphone was pointed towards the machine at a distance of 1 meter away from the source and at 1.5 meter above the ground. Figure 3 illustrates the SLM position in relation to the noise source. Manual distance measuring tape was used to measure the distances. Field observations were made during the measurements to observe and gather information on surrounding environment, tasks performed, external noise sources and condition of the machines. Information such as SLM serial number, make/model of the machine, measurement time, sound power level, LAeq, LAeq $_{min/max}$, tasks performed and control measures in place were recorded on the field-data sheet. The machines were grouped according to their make/model and their noise levels compared.

Equation 2 was used to calculate the logarithmic average noise level from multiple noise measurement values:

$$L_{Req,T} = 10 \log \frac{1}{n} \Sigma 10^{L_{Req,Ti}/10} \quad (2)$$

Where:

LReq, T	is the average equivalent continuous rating level
LReq, Ti	is the individual equivalent continuous rating level
n	is the total number of measurement positions (at least three)

Figure 3: SLM mounted on a tripod stand with the microphone pointing towards the source

3.5 Data management

Data on groundskeepers' demographic characteristics, work activities, lawn maintenance machines specifications, noise measurements, environmental conditions and existing noise control measures were manually captured on the field-data sheets and interview guides. As a back-up, the field-data sheets and interview guides were immediately scanned and saved into a password protected computer.

Once the collected raw data on the field-data sheets and interview guides was scanned through, it was securely stored in a fireproof steel cabinet in a locked office that has lock and key for a period of 12 months and thereafter, they will be destroyed via shredding machine. Data from field-data sheets and interview guides was manually entered onto Microsoft excel spreadsheet for further analysis.

The photographs of the lawn maintenance machines were taken using a digital camera with the capability to download the photographs into a computer using a USB cable. The photographs did not include faces of the participants. Data on personal noise measurements from noise dosimeter was downloaded onto the computer using a Casella software.

Hard copies of the field-data sheets and interview guides did not contain names of the participants.

3.6 Data analysis

STATA 17 SE statistical software was used to analyze the data collected from the interview guides and field-data sheets. Summary statistics was presented as frequencies-percentages for categorical variables and as mean and geometric standard deviation for continuous variables.

Formulas from the SANS 10083 standard were used to calculate parameters recorded from the measurements and to calculate noise levels using Microsoft Excel spreadsheet. Similarly, data from the noise dosimeter was recorded on the field data sheets and downloaded onto the computer using Casella software.

A one-way analysis of variance (ANOVA) was used to compare means between noise levels of different types of lawn maintenance machines. The ANOVA was performed at the alpha 0.05 level of significance and under the null hypothesis that there are no differences in noise levels produced by different types of lawn maintenance machines.

3.7 Ethical consideration

Prior to any engagement with research participants, ethical approval was sought from the Human Research Ethics Committee of the University of the Witwatersrand in Johannesburg. The ethics approval number for this study was M210242 MED21-01-104 (Appendix B). Written informed consent forms were completed and signed by the research participants prior to data collection. The purpose of the study was explained to the participants, with emphasis that the participation in the study is voluntary and that the participants can choose not to participate in the study with no harm coming to them.

In order to protect confidentiality of the participants, each worker was given a unique study number and only the unique number was used throughout the research project.

3.8 Quality control

All the noise measuring instruments (SLM, PND, sound calibrator) were externally calibrated by a SANAS 17025 accredited facility and the calibration was checked before and after each series of measurements, using a sound calibrator. A windshield suitable for the microphone was used to reduce the effect of ambient conditions on the microphone such as wind, dust and moisture.

Background (ambient) noise levels were taken using a SLM in order to ensure that the measurements are not affected by noise from extraneous sources such traffic noise or nearby construction activities.

The TSI VelociCalc hotwire-anemometer (model 9555-P, Shoreview, Minnesota, USA) and TSI Q-Trak monitor (model 7575-X, Shoreview, Minnesota, USA) instruments were externally calibrated by the SANAS ISO/IEC 17025 accredited laboratories.

The researcher is an Occupational Hygienist registered with the South African Institute of Occupational Hygiene (SAIOH) and has got more than 10 years practicing in the field of occupational hygiene, with relevant skills, knowledge and experience in conducting noise measurements.

CHAPTER FOUR: RESULTS

In this chapter, the results from noise measurements carried out to evaluate occupational noise exposure among groundskeepers at the three campuses of a public university in Gauteng are presented. Furthermore, this chapter provides results on the participants' demographic characteristics, environmental conditions that prevailed during noise measurements, description of lawn maintenance machines and elements of hearing conservation program practised to evaluate participants' awareness with regard to noise exposure.

4. Results

4.1 Demographic characteristics, work activities and work environment conditions

The first part of the results section provides a summary on the demographic characteristics of groundskeepers, the organisation of work in terms of daily activities and the environmental conditions to which work was performed under.

4.2 Demographic characteristics

Groundskeepers' demographic characteristics are presented in Table 1. The results showed that groundskeepers who participated in this study were all males and were permanently employed by the university. The majority, 89% (16 out of 18) of the groundskeepers had between 5 to 9 years of working experience in the current job, with only 6% having more than 10 years working experience. Campus C had most (7 out of 18) of the participants with years of working experience between 5 and 9, followed by campus B (5 out of 18) and campus C (4 out of 18).

Overall, 50% (9 out of 18) of groundskeepers in the three campuses fall between the age group of 36 and 45. Three out of 18 groundskeepers were above the age of 56 years. In terms of education level, all the participants had attained Senior Certificate or Matric. These may have positive implications for understanding of information and training material used for noise exposure awareness.

Table 1: Groundskeepers demographic characteristics

Variable	Campus A	Campus B	Campus C	Total
	n	n	n	N (%)
Age groups (years)				
26-35	-	1	2	3 (17)
36-45	4	2	3	9 (50)
46-55	1	-	2	3 (17)
56 and above	1	2	-	3 (17)
Experience in years				
< 5	1	-	-	-1 (5.5)
5 - 9	4	5	7	16 (89)
> 10	1	-	-	1 (5.5)
Minimum	2	5	5	2
Maximum	11	7	5	11

SD: Standard deviation; n: number of participants per campus; N: total number of participants

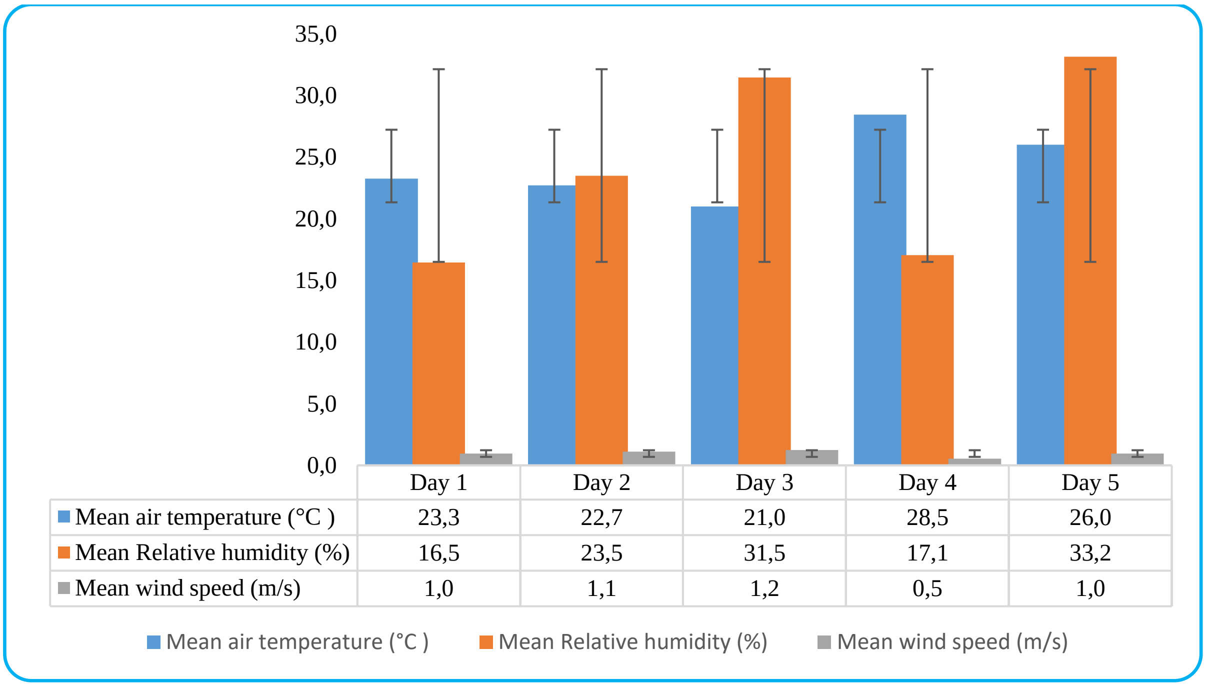
4.3 Work activities

Groundskeepers who worked at the three campuses operated different types of powered lawn maintenance machines as described in Table 2. Groundskeepers' normal work shift duration was 8-hour/day (7H00 – 15H30, Mon - Fri). Although their normal work shift was 8-hours per day, it is important to note that the duration of lawn maintenance activities varies daily depending on the size of the work area and the type of machine used.

4.4 Environmental conditions

Noise measuring instruments are very sensitive to environmental factors such as air temperature, relative humidity (RH) and wind speed and their performance and accuracy may be affected when these parameters are not within the required range.[(7)] The results of measured environmental conditions (air temperature, wind speed, relative humidity) revealed that, all the noise measuring instruments used were within their environmental specifications in line with the instrument manufacturer's instructions and the SANS 10083 standard.

Figure 4 illustrates summary of environmental conditions that prevailed during noise measurements at the three campuses. A more detailed results of environmental conditions are presented in Appendix G of this report.



	Day 1	Day 2	Day 3	Day 4	Day 5
Mean air temperature (°C)	23,3	22,7	21,0	28,5	26,0
Mean Relative humidity (%)	16,5	23,5	31,5	17,1	33,2
Mean wind speed (m/s)	1,0	1,1	1,2	0,5	1,0

Figure 4: The comparison of measured environmental conditions for data collection period

4.5 Lawn maintenance machines description

The characteristics of the different types of lawn maintenance machines used by groundskeepers at the three campuses are shown in Table 2. A total of 23 machines were assessed across the three campuses. The majority (60% or 14 out of 23) of the machines assessed were hand-held type, with STIHL brushcutters (n=7) dominating machines assessed. Ride-On machines were only used at campus A and C. On the other hand, push mowers were only used at campus B and C. All the machines were powered by petrol engines, except for Grasshopper Zero-Turn/526V which used diesel. Chainsaw/MS 382 used at Campus A had the highest engine speed of 3000 rpm and sound power level of 120 dBA. The primary source of noise in all the machines was the engine, whereas motorized cutter was identified as the secondary source of noise .[25] Of interest to note is that, the greater the engine speed (in rpm), the higher the sound power level. Engine speed of different machines as shown in Table 2, operate the motorized cutter and may change due to various factors such as engine size, type and depth of grass.

Sound power level (measured in Watt) is the preferred method for specifying noise emissions from the machines and is defined as the amount of energy radiated from the machine.[38]Generally, sound power level cannot be measured directly, however, it can be related to a sound pressure level.

About 60% (14 out of 23) of the machines assessed were more than 5 years old. Of the 23 machines assessed, it was found that all the ride-on (n=3) and push mowers (n=2) at campus C were more than 5 years old. A total of 8 machines (ride-on=2; hand-held=6) were assessed at campus A, and the results indicated that 75% (6 out of 8) were more than 3 years old. It was reported during data collection that all the machines were serviced as per the manufactures' instructions. Literature has proven that the age and maintenance level of the machines also influence the noise levels.[45]

Table 2: Machines used by Groundskeepers at the three campuses.

Machine type (make/model)	Machine age (year)	Engine speed (rpm)	Sound power level (dBA)	Campus
	Ride-On machine			
Baroness 5 Gang Fairway/LM2700	>5	2600	103	C
Grasshopper Zero-Turn/226V	>5	-	-	C
Grasshopper Zero-Turn/526V	>3	-	-	A
John Deere PrecicionCut/8700A	>3	2300	-	A
Cricket Pitch Roller/Series 2	>5	-	-	C
	Hand-held machine			
Backpack leaf blower/STIHL BR420	>5	2500	109	A and B
Brushcutter/STIHL FS400	>3	2800 - 12500	114	B and C
Brushcutter/STIHL FS250	>5	2800 - 7900	111	A and C
Brushcutter/STIHL FS280	>3	2800 - 12500	115	A
Brushcutter/STIHL FS280	>3	2800 - 12500	115	A
Chainsaw/MS 382	>3	3000	120	A
Leaf blower/STIHL BG56	>5	2500	104	B
Leaf blower/STIHL BG50	>5	2800	105	C
Hedge Trimmer/STIHL HS45	>5	2800 - 10300	104	A and C
	Push mower			

Tandem Aerovac Ratel/VX200	>1	-	-	B
Tandem/VX225	>5	-	-	C
Tandem cricket pitch mower	>5	-	-	C
Mfangano 5 speed/Elite 750	>5	-	-	B

dBA: A-weighted Decibel, rpm: revolutions per minute; -: data not available

4.6 Area noise measurements

Area noise monitoring results of the different types of machines used at the three campuses are presented in Table 3. The exceedance percentage is defined as the percentage of the TWA measurements exceeding 85 dBA (% > 85 dBA). A total of 17 area source noise measurements were taken at the three campuses under normal working conditions. Of the 17 area noise measurements taken, 7 (41.2%) were from Campus A, 5 (29.4%) from Campus B and C respectively.

Overall, about 71% (12 out of 17) of the measured machines emitted noise levels that exceeded the noise rating limit of 85 dBA. All the machines measured at the three campuses had an overall mean noise levels (LAeq) of 96.2 ± 7.5 dBA (Ranged 79.8 dBA – 104.5 dBA).

The results show that STIHL handheld Chainsaw/ MS 382 used at Campus A emitted the highest average noise level at 104.5 dBA, followed by Backpack leaf blower/BR420 at 100.3 dBA, also from Campus A. It was also noted that higher noise levels emitted by the chainsaw tended to coincide with higher sound power level (120 dBA) reported in Table 2. The lowest measured average noise level at 79.8 dBA was from Tandem Aerovac Ratel push-behind/VX200 machine measured Campus B. Machines used at Campus A accounted for the majority (35% or 6 out of 17) of noise levels above 85 dBA, followed by Campus C at 24% (4 out of 17) and Campus B 12% (2 out of 17). High variability (30% - 9000%) was observed between the three campuses in terms of percentage (%) of measurements exceeding 85 dBA, as shown in Table 3. STIHL handheld Chainsaw/ MS 382 at Campus A also had the highest exceedance percentage of > 85 dBA (9000%), while Tandem Aerovac Ratel push-behind/VX200 at Campus B had the lowest exceedance percentage > 85 dBA (30%).

Statistical analysis of the area noise measurements revealed that, for all noise producing machinery at the three campuses, there was no statistically significant differences on the measured noise levels ($P = 0.135$).

Table 3: Mean area source noise levels in the three campuses and percentage exceedance of noise rating limit

Campus	Machine measured	Measured Noise Level LAeq, dBA (±SD)	Minimum LAeq, dBA	Maximum LAeq,dBA	Exceedance percentage (%) ≥85 dBA
	Chainsaw/MS382	104.5 (±1.2)	103.3	105.6	9000
	Brushcutter/FS280	97.6 (±0.1)	97.5	97.7	1800
	Grasshopper Zero-Turn Ride-on/526V	88.9 (±0.3)	88.6	89,1	250
A	John Deere PrecicionCut Ride-on/8700A	84.1 (±0.4)	83,7	84,5	80
	Brushcutter/FS250	92.8 (±0.4)	92.4	93,1	600
	Hedge Trimmer/HS45	97.6 (±0.3)	97.4	97,9	1800
	Backpack leaf blower/BR420	100.3 (±0.1)	100.2	100,4	3500
	Brushcutter/FS400	92.0 (±0.9)	92	92,8	500
	Handheld leaf blower/BG56	82.1 (±0.2)	82,1	82,2	50
B	Backpack leaf blower/BR420	99.0 (±0.1)	98,9	99,1	2500
	Mfangano 5 speed walk behind/Elite 750	81.5 (±0.2)	81,2	81,6	50
	Tandem Aerovac Ratel push-behind/VX200	79.8 (±0.5)	79,3	80,3	30
	Protea Ride-on Cricket Pitch Roller/Series 2	88,6 (±0,6)	88	89,1	250
	Tandem push-behind cricket pitch mower	90,8 (±0,5)	90,2	91,2	400
C	Hedge Trimmer/HS45	96,7 (±0,5)	96,1	97,1	1500
	Tandem push-behind/Torx VX225	83,3 (±0,4)	82,8	83,6	60
	Baroness 5 Gang Fairway Ride-on/LM2700	85,8 (±0,5)	85,3	86,2	120

±SD: Standard deviation, LAeq: A-weighted equivalent continuous sound pressure level, dBA: decibel measured using A frequency-weighting

Results of area noise measurements are summarised inTable 4. The results show that among the 17 machines measured, 71% (n = 12) had noise levels above the noise rating limit of 85 dBA (ranged: 79.8 – 104.5 dBA). Overall, campus A had the highest mean area noise levels (98.8 dBA ±6.9) and exceedance percentage of > 85 dBA (2433%). These higher area noise levels in campus A tended to coincide with higher personal noise exposure levels (91.5 dBA ±4.7) also measured in campus A (Table 6).

Table 4: Summary of area noise measurements in three campuses

Campus	Number of machines measured (n)	Mean (±SD)	Min	Max	Percent (%)
		LAeq, dBA	LAeq, dBA	LAeq, dBA	>85 dBA
A	7	98.8 (±6.9)	84.1	104.5	2433
B	5	92.9 (±8.3)	79.8	99.0	626
C	5	91.6 (±5.1)	83.3	96.7	466

4.7 Task-based personal noise dosimetry measurements

A total of 18 PND measurements were conveniently collected from groundskeepers who operated lawn maintenance machines at the three university campuses. Out of the 18 PND measurements, 6 were measured at Campus A, 5 at Campus B and 7 at Campus C. Task-based personal noise monitoring results for groundskeepers who worked at the three campuses are reflected in Table 5. The 8-hour noise rating level (LAeq, 8h) and exceedance percentage parameters were calculated from the task-based measurements to enable accurate comparisons with the current legislation relative to the 8-hour exposure duration for the NIHL risk. Overall, campus A had the highest mean personal noise levels (91.5 dBA ±4.7) and peak noise levels of 132.7 dBC ±7.2.

A total of 2653 minutes or 44 hours of personal noise dosimetry sampling time were conducted from all 18 samples over a period of five days (Table 5). The mean sampling time for all the 18 samples was about 147 minutes or 2.4 hours (ranged: 67 – 234 minutes). In order to compare the measured equivalent continuous A-weighted sound pressure level (LAeq) with 8-hour noise rating limit of 85 dBA, task-based measurements were normalized to a nominal 8-hour equivalent sound pressure level as preferred parameters for quantifying personal noise exposure. The average exposure duration of 6-hours which was reported by the participants during noise measurements, was used to calculate the time-weighted average 8-hour equivalent noise exposure levels.

Out of the 18 PND measurements taken at the three campuses, 14 (78%) exceeded the noise rating limit of 85 dBA. The mean 8-hour time-weighted average noise rating level (LAeq, 8h) for all the three campuses was of 89.8 ± 2.3 dBA (Ranged 81.7 – 96.0 dBA), which exceeded the noise rating limit of 85 dBA. Employees who worked at Campus A had the highest mean noise level (LAeq, 8h) of 91.5 ±4.7 dBA, followed by 89.1 ±4.0 at Campus B and 86.9 ±2.9 at Campus C (Table 4). The highest PND noise level (LAeq, 8h) was recorded at 96.0 dBA on an employee who operated Backpack leaf blower/BR420 machine at Campus A. Employee who operated Baroness 5 Gang Fairway Ride-on/LM2700 machine at Campus C had the lowest noise exposure at 81.7 dBA. The employee who operated Backpack leaf blower/BR420 machine at Campus A had the highest exceedance percentage of > 85 dBA (1200%), while the one who operated Baroness 5 Gang Fairway Ride-on/LM2700 at Campus C had the lowest exceedance percentage > 85 dBA (50%).

The mean peak or highest instantaneous sound pressure level (LCpeak) of 131.3 dB ± 5.5 dB (ranged: 115.6 – 140 dB) was recorded from all 18 samples (Table 5). Groundkeeper who operated Backpack leaf blower/BR420 machine at Campus A had the highest peak sound pressure noise level (LCpeak) of 140 dB. According to OSHA Occupational Noise Standard, exposure to noise levels above 140 dB can cause immediate damage to hearing and should not be exceeded at no time during the day.[11]

Statistical analysis using a one-way analysis of variance (ANOVA) was carried out to determine whether a significant difference existed between the personal noise exposures levels measured at the three university campuses. The overall difference in the mean 8-hour TWA personal noise exposure level (LAeq, 8h) and peak sound pressure level (LCpeak) were found to be not significant for both the LAeq, 8h (P = 0.304) and LCpeak (P = 0.607).

Table 5: Task-based personal noise exposure levels measured at the three Campuses and percentage exceedance of noise rating limit

Campus	Machine Operated	Sampling Duration	Measured Noise Level		8 Hour Noise Rating Level	Exceedance Percentage
		Minutes	LAeq, dBA	LCpeak,	LAeq, 8h	≥85 dBA
	Brushcutter/FS280	234	92.1	122.2	90,9	400
	Brushcutter/FS250	201	84.5	119.7	83,3	60
A	Brushcutter/FS280	67	94.1	124.0	92,9	600
	Grasshopper Zero-Turn Ride-on/526V	151	90.3	126.2	89,1	250
	John Deere PrecicionCut Ride-on/8700A	142	86.5	123.2	85,3	110
	Backpack leaf blower/BR420	105	97.2	140	96,0	1200
	Tandem Aerovac Ratel push-behind/VX200	118	86.4	133.6	85,2	100
	Mfangano 5 speed walk behind /Elite 750	185	89.9	124.3	88,7	250
B	Backpack leaf blower/BR420	137	94.2	119.1	93,0	600
	Handheld leaf blower/BG56	146	83.7	115.6	82,5	60
	Brushcutter/FS400	197	90.3	138.5	89,1	250
	Baroness 5 Gang Fairway Ride-on/LM2700	121	82.9	117.9	81,7	50

	Brushcutter/FS250	146	84.1	124.6	82,9	60
	Brushcutter/FS250	136	90.9	125.8	89,7	300
C	Brushcutter/FS400	118	89.1	124.4	87,9	200
	Handheld leaf blower/BG50	203	86.6	122.6	85,4	110
	Grasshopper Zero-Turn Ride-on/226V	115	88.0	122.5	86,8	150
	Protea Cricket Pitch Roller Ride-on/series 2	131	89.5	121.5	88,3	200

LCpeak: C-weighted peak sound pressure level, LAeq: A-weighted equivalent continuous sound pressure level, dBA: decibel measured using A frequency-weighting

Note: The personal noise dosimeter was placed on the worker's shoulder, close to the ear and measurements were taken over a sufficiently long time to be representative of the worker's exposure

In Table 6 a summary on the average noise level for the three noise level rating scale is presented. The average noise level between campus A and Campus c varied by a margin of over 50% when using the average Laeq.

Table 6: Summary of task-based personal noise exposure measurements

Campus	Number of samples taken (n)	Mean (±SD)		
		LAeq, dBA	LCpeak	LAeq, 8h
A	6	92.7 (±4.7)	132.7 (±7.2)	91.5 (±4.7)
B	5	90.3 (±4.0)	132.9 (±9.6)	89.1 (±4.0)
C	7	88.1 (±2.9)	123.3 (±2.6)	86.9 (±2.9)

±SD: Standard deviation, LAeq: A-weighted equivalent continuous sound pressure level, dBA: decibel measured using A frequency-weighting, LCpeak: C-weighted peak sound pressure level

4.8 Estimation of the risk of noise induced hearing loss

The probability of NIHL arising from noise exposure during operation of lawn maintenance machines was estimated using the Five-Step Simple/Flexible risk assessment method, adopted from Reinhold and Tint, 2009 as in Table 7.[(54)]

The NIHL risk rating levels for employees who operated various machines at the three campuses is presented in Table 6. The estimation NIHL risk among the employees at the three campuses shows that majority (50%) of the employees were exposed to noise levels between 87 dBA and 95 dBA, which is classified as inadmissible risk. The maximum exposure with noise exposure criteria above 95 dBA was observed at campus A, while the rest of the campuses there was no exposure above 95 dBA as in Table 7. Research shows that 8-hour average daily noise exposure levels between 75 dBA and 80 dBA are unlikely to cause hearing loss.[(3)] Out of the 18 employees who were assessed for personal noise exposure at the three campuses, none was exposed to noise levels below 80 dBA.

Table 7: Personal noise exposure risk rating levels for groundskeepers

Noise exposure criteria, LAeq, 8h	**Risk level**	**Number of exposed workers at campus A (%)**	**Number of exposed workers at campus B (%)**	**Number of exposed workers at campus C (%)**
< 80	Tolerable risk	None	None	None
80 - 85	Justified risk	1 (16,66)	1 (20)	2 (28.57)
85 - 87	Unjustified risk	1 (16,66)	1 (20)	2 (28.57)
87 - 95	Inadmissible risk	3 (50)	3 (60)	3 (42.85)
> 95	Intolerable risk	1 (16,66)	None	None

4.9 Groundskeepers' awareness on noise exposure

As shown in Table 8, which focuses on groundskeepers' information and training, 95% (19 out of 20) of the total groundskeepers at the three campuses reported that, they were not trained about the noise rating limit or occupational exposure limit for noise and its meaning. Furthermore, 50% of groundskeepers reported that, they never received information and training on the health effects of noise exposure while employed at the university. It is worth noting that, even though 50% of groundskeepers reported not receiving information and training on the health effects of noise exposure, majority (75%) reported that, they know about the health effects of noise exposure.

Table 8: Summary of groundskeepers' responses to information and training questions

Question	Campus A, N= 6		Campus B, N= 5		Campus C, N= 9	
	Yes (%)	**No (%)**	**Yes (%)**	**No (%)**	**Yes (%)**	**No (%)**
Information and training						
Have you ever received information and training on the effects of noise on hearing while working here?	4 (66.7)	2 (33.3)	1 (20)	4 (80)	5 (55.6)	4 (44.4)
Do you know about the health effects of noise exposure?	4 (66.7)	2 (33.3)	5 (100)	0	6 (66.7)	3 (33.3)
Were you trained on how to wear, use and care for your hearing protective devices (HDPs)?	5 (83.3)	1 (16.7)	3 (60)	2 (40)	3 (33.3)	6 (66.7)
Have you been informed of the necessity and limitations of HPDs?	5 (83.3)	1 (16.7)	3 (60)	2 (40)	3 (33.3)	6 (66.7)
Were you trained about the noise-rating limit and its meaning?	0	6 (100)	0	5 (100)	1 (11.1)	8 (88.9)

Table 9, which focuses on groundskeepers' responses regarding HPDs, shows that majority (95% or 18 out of 19) of the total employees reported that, they think there is value in wearing HPDs. Notably, 90% of groundskeepers reported that, there is no one who is checking and supervising if they wore HPDs while operating lawn maintenance machines. The analysis further shows that, 47% of groundskeepers reported that, their HDPs were not comfortable when worn. Majority (63%) of groundskeepers reported that, they use HPDs while operating noisy machines. It was identified during data collection that, majority (56%) of groundskeepers were provided with earmuffs as a form of hearing protection. The provided earmuffs did not have brand names and technical specifications. Only a few of STIHL helmet mounted earmuffs had brand names and technical specifications. The STILH helmet mounted earmuffs were assigned with a single number raring (SNR) of 24. The SNR method is a European system of determining the expected attenuation of HPDs.

Table 9: Summary of groundskeepers' responses to hearing protection devices questions

Question	Campus A, N= 6		Campus B, N= 5		Campus C, N= 8	
	Yes (%)	No (%)	Yes (%)	No (%)	Yes (%)	No (%)
Hearing protection devices						
Do you use hearing protective devices (HPDs) in your job?	4 (66.7)	2 (33.3)	4 (80)	1 (20)	4 (50)	4 (50)
Did anyone explain why you need to wear HPDs?	5 (83.3)	1 (16.7)	3 (60)	2 (40)	3 (37.5)	5 (62.5)
Does anyone check if you are wearing your HPDs?	1 (16.7)	5 (83.3)	0	5 (100)	1 (12.5)	7 (87.5)
Do you store your HPDs after each use in a clean area?	4 (66.7)	2 (33.3)	4 (80)	1 (20)	4 (50)	4 (50)
Do you routinely get new HDPs when it wears out?	4 (66.7)	2 (33.3)	4 (80)	1 (20)	3 (37.5)	5 (62.5)
Are your HPDs comfortable when worn?	3 (50)	3 (50)	4 (80)	1 (20)	3 (37.5)	5 (62.5)
Do you have any difficulty using your HPDs?	1 (16.7)	5 (83.3)	0	5 (100)	1 (12.5)	7 (87.5)
Are you aware of a procedure for reporting and replacing defective HPDs?	6 (100)	0	5 (100)	0	1 (12.5)	7 (87.5)
Do you think there is any value in wearing HPDs?	6 (100)	0	4 (80)	1 (20)	8 (100)	0

Table 10 depicts results of responses relating to groundskeepers' audiometric testing. The analysis shows that that 78% (14 out of 18) of the total groundskeepers indicated that, they were given audiometric testing while employed at the university. All groundskeepers reported that, they do not perform leisure/ recreational activities involving loud noise outside work.

Table 10: Summary of groundskeepers' responses to audiometric testing questions

Question	Campus A, N= 5		Campus B, N= 5		Campus C, N= 8	
	Yes (%)	No (%)	Yes (%)	No (%)	Yes (%)	No (%)
Audiometric testing						
Have you ever been given a hearing test while working here?	5 (100)	0	4 (80)	1 (20)	5 (62.5)	3 (37.5)
Do you perform leisure/recreational activities involving loud noise outside work?	0	5 (100)	0	5 (100)	0	8 (100)

CHAPTER FIVE: DISCUSSION AND CONCLUSION

This chapter discusses key findings from the study as presented according to the listed objectives. Furthermore, the strengths and limitations of the study design, methodology and results are discussed. As part of the study, practical recommendations are made for the systematic and integrated management of occupational noise exposure among groundskeepers. The chapter ends with conclusion by highlighting the scholarly contribution and policy impacts of this study.

5. Discussion and Conclusion

Occupational noise exposure is one of the most frequent health hazards present in the workplace with significant health problems and economic consequences.(1) There is sufficient scientific evidence indicating that excessive and prolonged noise exposure can result in permanent hearing loss, hypertension and ischemic heart disease, among other effects.(56) Although regulations and occupational exposure limits for noise have been in place for decades, the prevalence of noise exposures and NIHL remains high.(1) Operators of lawn maintenance machines, like brushcutters and leaf blowers, are particularly exposed to excessive noise levels.

Noise exposure levels need to be quantified to determined which employees need to be included in the hearing conservation programs (HCP). HCP have been identified as solutions to the high burden of NIHL in industries where workers are exposed to excessive noise.(57) The aim of this study was to evaluate occupational noise exposure and hearing conservation practices among groundskeepers within the three campuses.

The results of this study consist of groundskeepers' demographic characteristics, description of lawn maintenance machines, area and personal noise exposure levels and employee awareness with regard to noise exposure. Area and personal noise exposure levels allowed comparison to the noise rating limit of 85 dBA, in order to determine which employees would be at risk of developing NIHL.

5.1 Synopsis of study findings

This study provides data about measured occupational noise exposure levels (area and personal) in three campuses of a public university in Gauteng. The results of this study demonstrated that out of the 18 personal noise exposure measurements taken in the three campuses, 78% (n=14) exceeded the legislated noise rating limit of 85 dBA (ranged: 81.7 dBA – 96.0 dBA), thus increasing groundskeepers' risk to NIHL. The risk of NIHL was estimated using the Five-Step Simple/Flexible risk assessment method[(54)] and it was found that 50% (9 out 18) of the groundskeepers were exposed to noise levels between 87 dBA and 95 dBA, which is classified as inadmissible risk as per the adopted risk assessment method. Furthermore, 71% (12 out of 17) of the measured area noise levels in all three campuses were found to be above the noise rating limit of 85 dBA (ranged:79.8 dBA – 104.5 dBA), which agreed with this study's hypothesis.

5.1.1 *Demographic characteristics of study participants*

Table 1 shows a summary of participants' demographic characteristics. The findings of this study demonstrated that the study participants comprised a total of 18 males, with mean working experience in the current job of five (5) years (ranged 2 – 11 years). Majority (50% or 9 out 18) of the participants were aged between 36–45, while only 16% (n=3) were above the age of 56. The distribution of the participants according to their education was 100% secondary school. This may have positive implications for understanding of information and training material used for noise exposure awareness.[(58)]

5.1.2 *Area noise exposure levels in three campuses*

The current noise exposure limit specified in South African NIHL Regulations[(14)] is 85 dBA over an 8-hour working day. It was shown in the present study that, majority (71%) of the measured area noise levels in the three campuses exceeded the noise rating limit of 85 dBA. The range of area noise levels was between 79.8 dBA to 104.5 dBA as shown in Table 4. STIHL chainsaw/ MS 382 that was used at campus A presented the highest noise levels (104.5 dBA ±1.2). The results of this study showed that chainsaw had the highest engine speed of 3000 rpm when compared to all machines assessed. These findings are in agreement with a study conducted by Mallick et al[(22)], which affirmed that grass-trimming machines with high engine speed (in rpm) were more likely to produce high noise levels. These results showed that area noise levels measured in the three campuses were lower (71%) than those found in the study conducted by Balanay et al[(21)] who assessed noise exposure of groundkeepers in North Carolina Public Universities and found that 82% of the measured machines or area noise levels exceeded the noise rating limit of 85 dBA. Although area noise levels found in this study were lower than those reported by Balanay et al, both studies found that majority of area noise levels exceeded the noise rating limit of 85 dBA.

The commonly used machines in the three campuses included hand-held STIHL Brushcutters (92.0 dBA – 97.6 dBA), STIHL Leafblowers (82.1 dBA – 100.3 dBA) and STIHL Hedge trimmers (96.7 dBA – 97.6 dBA). These findings are similar to those in a study conducted by Root et al(59) on firefifgter noise exposure during trianing activities and general equipment use, including lawn maiteance machines. The noise levels measured for leaf blower (94 dBA), string trimmer (96 dBA), chainsaw (105 dBA) and lawn mower (87 dBA), which are comparable to those measured in the current study (leaf blower = 99 dBA, string/hedge trimmer = 97.6 dBA, chainsaw = 104.5 dBA, lawn mower = 88.9 dBA). A pilot study conducted by Balanay et al(60) identified ride-on mower as one of the most commonly used machine by groundskeepers. However, in this study, it was found that the most commonly used machine in the three campuses was hand-held brushcutter.

The average area noise levels obtained in the three campuses were shown to be not significantly diffiferent (P = 0.304). The distribution of measured area noise levels indicated that the mean noise levels per campus were recorded at 98.8 dBA (campus A), 92.9 dBA (campus B) and 91.6 dBA (campus C). Considering the lower differences in noise levels between the three campuses, particularly between campus B and C, this may suggest that groundskeepers were more likely exposed to noise levels of low variability. Another factor that may have contributed to lower differences in noise levels is that groundskeepers more likely use a single machine throughout the work shift.

The use of different types of lawn maintenance machines may emit different noise levels due to various factors such as, make/model of the machine, engine size, acoustic properties of the surroundings (e.g. free field or reverberant field), age of the machine, ground conditions and type of the grass. These factors may inherently contribute to differences in groundskeepers' noise exposure.(22) Therefore, noise output of the machinery should form part of the selection criteria when investing in lawn maintenance machines.

5.1.3 *Personal noise (task-based) exposure levels in the three campuses*

The results of this study indicated that, of the 18 personal noise exposure measurements taken, 14 (78%) were higher than the occupational exposure limit of 85 dBA. The highest personal noise exposure level (96.0 dBA) was found on one of the groundskeepers who operated backpack leaf blower/BR420 machine at Campus A. The current study's findings support the work of Hanidza et al(32) who investigated noise exposure among grass cutting workers in Malaysia. The study found that 15 out of 18 (83.3%) grass cutters 8-hour noise exposure levels exceeded the noise rating limit of 85 dBA. Although personal noise exposure levels found in this study were lower (in terms of percentages) than those reported by Hanidza et al, both studies found that majority of personal exposure noise levels exceeded the noise rating limit of 85 dBA. The mean peak or highest instantaneous sound pressure level (LCpeak) was 131.3 dB ± 5.5 dB (ranged: 115.6 – 140 dB). Similar findings were documented in a study conducted by Haron et al[28], which looked at occupational noise exposure among leaf blower and grass cutter workers in public university. The study found the range of 8-hour noise exposure levels was 84.4 dBA to 95.8 dBA. Research shows that 8-hour average noise levels below 75 dBA or peak noise levels below 130 dBC are unlikely to cause hearing loss.[1, 37] Exposure to peak noise levels above 140 dBC can cause immediate damage to hearing.[11] NIOSH estimates a risk of NIHL after a 40 year working lifetime of 1% at 80 dBA, 8% at 85 dBA and 25% at 90 dBA.[11]

Table 6 present summaries of personal noise exposure levels measured at the three university campuses. Campus A was found to have the highest average 8-hour equivalent continuous noise rating level (LAeq, 8h) of 91.5 ±4.7 dBA, followed by 89.1 ±4.0 at Campus B and 86.9 ±2.9 at Campus C. These average noise levels exceeded the noise rating limit of 85 dBA. In terms of the noise rating limit exceedance percentage, the groundskeeper who operated backpack leaf blower/ MS 382 machine was found to have the highest exceedance percentage of > 85 dBA (1200%). However, it should be noted that the personal noise dose contribution depends on the duration of exposure operating the machine. The mean personal noise measurement duration for all the 18 samples was approximately 147 minutes or 2.4 hours (ranged: 67 – 234 minutes). Although the measurement duration for all the samples was less than 8 hours, the noise measurements captured representative noise exposure levels of machine operators. It was difficult to determine for how long the machines were going to be used due to the variable nature of grass cutting tasks. Noise exposure results with shorter duration were normalized to an 8-hour day to allow for direct comparison with regulated noise rating limit of 85 dBA, which is based on an 8-hour day. For example, employees who operate ride-on machines usually covers large areas, thus resulting in increased duration of noise exposure. Manual operation of the machines usually requires the employees to cover small areas, thus resulting in limited exposure duration to noise.

Data from each of the three campuses were analysed using an ANOVA. The test indicated P-value of 0.304 for 8-hour TWA personal noise exposure level (LAeq, 8h) and 0.607 for peak sound pressure level (LCpeak). There were no significant differences in noise exposure between the three campuses. With this study demonstrating the excessive noise exposure among groundskeepers, it is essential for the university to establish an effective hearing conservation program to reduce the employees' risk of noise induced hearing loss.

5.1.4 *Estimation of noise induced hearing loss risk*

Measurements of noise exposures using different metrics such as C or A frequency weighting networks, including variability of noise exposure profile, can result in different outcomes regarding noise induced hearing loss (NIHL) risk.(61) Scientific literature shows that the best measure of NIHL risk is sound pressure noise level measured using A-frequency weighting network (e.g. dBA) and this remains the metric of choice in most assessments of occupational noise.(11) In this current study, A-frequency weighting network was used in all the measurements. Regulations for most occupational noise exposure, including the South African NIHL Regulations, are in terms of the A-weighted sound level.(62) Furthermore, there is sufficient scientific evidence indicating that excessive noise exposure can cause NIHL.(2) The WHO also reported that 16% of the disabling hearing loss in adults is attributed to excessive noise exposure.(3) Based on the noise exposure levels reported in this current study, it is evident that majority of the machine operators are at risk of NIHL.

Tables 5 shows personal noise exposure risk rating levels for groundskeepers at campus A, B and C. Groundskeepers' estimation of NIHL risk was determined using the Five-step Simple/ Flexible risk assessment method(54). According to the risk rating method, 50% (9 out of 18) groundskeepers were exposed inadmissible risk noise levels between 87 dBA and 95 dBA, implying that these employees are at risk of NIHL and severe sleeping disturbances.

5.2 **Controls in place or lack thereof**

5.2.1 *Noise measurements and exposure assessment*

The Noise Induced Hearing Loss Regulations (2003) of the Occupational Health and Safety Act (No 85 of 1993) requires that no employer shall require or permit any person to enter any workplace under his or her control where such person will be exposed to noise levels at or above the 85 dBA noise-rating limit. The NIHL Regulations further states that, where the noise exposure assessment or a review of such assessment indicates that any employee may be exposed to noise at or above the noise-rating limit, an employer shall ensure that, a measurement programme of noise exposure at that workplace is undertaken to identify potentially hazardous noise levels and personnel at risk.(14)

5.2.2 *Engineering controls*

According to the NIHL Regulations(14), engineering noise controls must be applied as the preferred means to prevent or reduce noise at the source or along its transmission path. Based on the findings of this study, it was found that, all the lawn maintenance machines used at the university undergo regular servicing and maintenance. Regular maintenance of machines such as balancing, lubricating and adjusting of machines is important as the machines' performance deteriorate with age and can become noisier.[38] Majority of the machines used at the university were gasoline-powered and generated noise levels ranging between 79.8 dBA to 104.5 dBA. As an engineering control strategy, it is highly recommended that the university participate in "Buy Quiet Program" when new equipment is purchased. "Buy Quiet Program" is one of the most cost-effective ways of reducing noise in the workplace and can be done by obtaining relevant information on equipment noise emissions (for example, data on sound power level and sound pressure level) from the manufacture and compare it to determine the quietest machine.[21]

5.2.3 *Information and training*

Information and training is important to the overall success of a hearing conservation program. An understanding by employees of the permanent nature of NIHL and their responsibilities under the program are all essential for the success of the program.[34] Table 8 present summaries of employee responses to on questions related to information and training. It emerged, from the findings of the current study that, 95% (19 out of 20) employees indicated that they were not trained about the noise rating limit and its meaning as required by Regulation 4 of the NIHL Regulations. Furthermore, it was found that, 50% of the employees indicated that they never received information and training on the health effects of noise exposure while working at the university. One of the critical findings of this study is that 95% of the employees did not know about the noise rating limit and its meaning. Regulation 4 of the NIHL Regulations requires employers to provide information and training for all employees who may be exposed to noise at or above the noise rating limit, which incorporates, among others, the noise rating limit and its meaning.[14]

5.2.4 *Audiometric testing*

Table 10 depicts results of responses relating to employee audiometric testing. The results of the study revealed that 78% (14 out of 18) employees indicated that, they were given audiometric testing while employed at the university. Audiometric testing is normally conducted to monitor the effectiveness of the hearing conservation program and it also helps in the early detection of hearing loss that will allow for further corrective measures before permanent hearing loss occurs.[63]

5.2.5 *Using hearing protection devices*

Table 9 shows results of groundskeepers' responses relating to use of hearing protection devices (HPDs). The results indicated that majority (63%) of groundskeepers reported that, they use HPDs while operating noisy machines. Notably, 90% of groundskeepers reported that, there is no one who is checking and supervising if they wore HPDs while operating lawn maintenance machines. The analysis further shows that, 47% of the employees reported that, their HDPs were not comfortable when worn. HPDs are used to reduce the level of noise reaching the inner ear, particularly when the risk of noise exposure cannot be eliminated or minimized by other means of controls such as engineering control. Areas where employees may be exposed to high noise levels should be demarcated as noise zones, for example, in terms of lawn maintenance machines, a prominent mandatory symbolic sign for hearing protection should be posted on the machines, indicating that HPDs should be worn when operating them.[14, 58]

5.3 Study limitations

The study sites were localized to include only three campuses. Therefore, the results of this study may not be generalized to groundskeepers at other public universities due to the small population size. This study focused on lawn maintenance activities that took place during rainy season (September and November) only. The rainy season was chosen due to anticipated abundant rainfall during these periods, which resulted in more frequent grass cutting activities [38]

Noise levels generated by lawn maintenance activities during rainy season may vary when compared to dry season due to differences in grass conditions, frequency and duration of lawn maintenance activities.[22]

Personal noise dosimeters were mounted on the shoulders of the employees during the measurements and these might lead to reflection of noise from the body of the employee or head, which was in close proximity to the microphone.

5.4 Study strengths

This study helps fill a gap in the literature, particularly in South Africa, on occupational noise exposure among groundskeepers employed in public universities. According to researcher's knowledge, this study was the first to assess noise exposure among groundskeepers in South African higher learning institution. Research studies on noise exposure among groundkeepers are limited and no current published research studies were found in South Africa. Groundskeepers are regarded as vulnerable group of workers and this study has demonstrated that they are exposed to excessive noise levels above legislated limit of 85 dBA. This study assessed groundskeepers employed at three different campuses, which differed in terms of land size and landscaping features, in order to obtain representative measurements.

Results from this study will also be beneficial to the university management and groundskeepers by giving them an opportunity to further understand and appreciate the extend of noise exposure levels emitted by the different types of lawn maintenance machines and help to identify, manage and characterize machinery emitting high noise levels (e.g. "by implementing a "Buy Quite Program"). Furthermore, the findings of the study may serve as a basis for policy formulation and contribution to the effectiveness of hearing conservation program.

5.5 Recommendations for future research

Future studies covering more universities are needed to collect additional noise exposure data (both area and personal) from a bigger groundskeeper population. Additionally, further investigation on the contributory factors to noise exposure such as condition of the grass, machine engine size and extended exposure duration should be conducted. This will be of great benefit to the advancement of science and improvement of the body of knowledge on compliance with the occupational health and safety regulations.

Future research should also examine the current hearing status of groundskeepers in order to monitor the effectiveness of hearing conservation programs.

5.6 Recommendations

Protection from excessive noise in the workplace requires efforts by both the employer and employees. With this study demonstrating the excessive of groundskeepers to noise, it is important for the university management to establish an effective hearing conservation program as required by the NIHL Regulations and SANS 10083 Code of Practice.[14, 34] The following recommendations are made to assist the management of the university in controlling groundskeepers' exposure to noise:

- A noise exposure and assessment monitoring program designed to regularly monitor groundskeepers' noise exposure should be established to identify employees who need to be enrolled in the university's hearing conservation program as per the NIHL Regulations.
- As part of engineering control strategy, it is recommended that the university participate in "Buy Quiet Program" such as the one introduced by the NIOSH when purchasing new lawn maintenance machinery This can be done by requesting noise level specifications from equipment and machinery manufacturers, and including these noise level data in bid/tender evaluations. The cost/benefit relationship should be examined

in each case. It often makes business sense to make an initial investment in quiet equipment, rather than having to deal with the consequences of employees' hearing loss later on.

- Regular maintenance of the machines is important to reduce noise at the source. Badly worn machine components such as bearings, loose parts, poor lubrication, exhaust noise and unbalanced rotating parts can be reduced with good maintenance.
- Retrofitting the operator's cabs of ride-on machinery such as tractors, riding mowers is important in reducing noise exposure
- Limit the amount of time a groundskeeper operates lawn maintenance machines, with the aim of reducing the daily noise exposure. For example, machine operators can mow the grass for about 2 hours a day and perform other less noisy duties such as watering the garden.
- Machine operators should be encouraged not to operate the machines in groups by keeping sufficient distance between them. For example, by placing operators at least 15 meters apart could reduce the noise levels to certain extent.
- Ensure that all identified noisy machines are posted with mandatory symbolic sign for hearing protection in order to remind the employees to wear hearing protection.
- Maintain the current practice of conduct audiometric testing to all groundskeepers who are exposed to noise at or above the noise-rating limit of 85 dBA annually, or as specified in the NIHL Regulations.
- The NIHL Regulations require that whenever employees are exposed to noise levels above 85 dBA, feasible engineering or administrative controls should be used to reduce the noise levels. The use of HDPs should be regarded as the last resort when it is not possible to reduce the noise to acceptable levels by other means. HPDs must be provided to all groundskeepers at no cost to them and they must have sufficient noise reducing rating that will reduce employees' noise exposure to below 85 dBA.
- Ensure that all groundskeepers who operate noisy machinery are trained on the potential risks to health associated with noise exposure, its sources and the meaning of noise-rating limit for hearing conservation, including the fact that there are often no symptoms of overexposure to noise. Inform and train all the employees required to wear hearing protection, on the proper selection, necessity, correct use, maintenance and limitations of hearing protective devices, including practical demonstration of fitting HPDs

properly. Appropriate refresher training should be conducted at least annually. Training must be given by a competent person.

5.7 CONCLUSION

This chapter summarizes the significant findings of the current study. The findings of this study have clearly highlighted that, although the university had hearing conservation programs in place, there were shortcomings in the implementation of some elements of the program, in particular with regard to information and training, noise exposure monitoring and use of hearing protection devices. Most groundskeepers were exposed to noise levels exceeding the noise rating limit of 85 dBA and were at risk of acquiring NIHL. When considering the peak noise levels, the results of the study showed that there was only one groundskeeper who was exposed to noise levels exceeding the peak limit of 140 dBC. In all cases, employees should never be exposed to peak noise levels in excess of 140 dBC.(11) Prevention, by reducing the noise exposure via engineering measures should be prioritized.

No significant differences were found in the average area and personal noise levels measured in the three campuses. However, the use of certain machines such as backpack leaf blower and chainsaw were shown to be associated with high noise exposure levels. Therefore, it is essential to ensure that noise levels on the lawn maiteance machines are signficalty reduced by implamanting good maiteance practices and buy quiet program.

Reducing noise exposure among groundskeepers can and should be achieved through noise exposure awareness such as information and training, routine noise exposure monitoring and provision of adequate hearing protection devices. The study has demonstrated the need to implement effective hearing conservation program in the university to reduce the risk of NIHL, which should cover noise monitoring, engineering controls, information and training, audiometric testing and hearing protection devices.

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7. APPENDICES

7.1 Appendix A: Plagiarism declaration form

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

FACULTY OF HEALTH SCIENCES

PLAGIARISM DECLARATION TO BE SIGNED BY ALL HIGHER DEGREE STUDENTS

SENATE PLAGIARISM POLICY: APPENDIX ONE

I Moses Mokone (Student number: 1818890) am a student registered for the degree of MPH - Occupational Hygiene in the academic year 2023.

I hereby declare the following:

- I am aware that plagiarism (the use of someone else's work without their permission and/or without acknowledging the original source) is wrong.
- I confirm that the work submitted for assessment for the above degree is my own unaided work except where I have explicitly indicated otherwise.
- I have followed the required conventions in referencing the thoughts and ideas of others.
- I understand that the University of the Witwatersrand may take disciplinary action against me if there is a belief that this is not my own unaided work or that I have failed to acknowledge the source of the ideas or words in my writing.
- I have included as an appendix a report from "Turnitin" (or other approved plagiarism detection) software indicating the level of plagiarism in my research document.

Signature: ____________ Date: 12.01.2023

7.2 Appendix B: Research ethics clearance certificate

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

R14/49 Mr Moses Mokone et al

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

CLEARANCE CERTIFICATE NO. M210242 MED21-01-104

NAME: (Principal Investigator)	Mr Moses Mokone et al
DEPARTMENT:	Occupational Health
PROJECT TITLE:	Occupational noise exposure among groundskeepers at a public university in Gauteng, South Africa
DATE CONSIDERED:	26/02/2021
DECISION:	Approved unconditionally
CONDITIONS:	
SUPERVISOR:	Dr Daniel Masekameni
APPROVED BY:	Dr C Penny, Chairperson, HREC (Medical)
DATE OF APPROVAL:	09/06/2021

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 Research Office Secretary in Room 301, Third floor, Faculty of Health Sciences, Phillip Tobias Building, 29 Princess of Wales Terrace, Parktown, 2193, University of the Witwatersrand. 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.** The date for annual re-certification will be one year after the date of convened meeting where the study was initially reviewed. In this case, the study was initially reviewed February and will therefore be due in the month of February each year. Unreported changes to the application may invalidate the clearance given by the HREC (Medical).

Principal Investigator Signature

18/06/2021
Date

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES

7.3 Appendix C: Participant Information Sheet

Study title: Occupational noise exposure among groundskeepers at a public university in Gauteng, South Africa

Good day!

Nature and purpose of the study

My name is Mr Moses Mokone and I am a Masters student at the University of the Witwatersrand, Johannesburg, studying for Masters in Public Health, under the supervision of Dr Daniel Masekameni, specialising in Occupational Hygiene. As part of my studies, I have to undertake a research project and write a report, which may be published. I am investigating occupational noise exposure among groundskeepers who operate various lawn maintenance machines at the three Wits University campuses. The aim of this research project is to evaluate noise exposure levels for groundskeepers who operate different types of powered lawn maintenance machines at the three Wits University campuses and estimate their risk of noise-induced hearing loss. In short, I want to understand what noise hazards are present in your job and whether your employer is taking all reasonable precautions to minimise your exposure to such hazards. This investigation will involve (a) asking you for some basic biographical data about yourself and (b) taking of personal and source noise measurements during lawn maintenance activities, using noise dosimeters and an integrating sound level meter.

A variety of lawn maintenance machines are widely used by workers in landscaping and gardening sectors to beatify and upkeep the physical environment in areas such as community parks, sporting grounds and universities. However, it is evident that the increased use of noisy outdoor powered lawn maintenance machines (ride-on mowers, push mowers, brush cutters, tractors and leaf blowers) is a major source of high noise exposure and despite the aesthetical beauty outputs from this activity, puts the workers at a greater risk of suffering from permanent hearing loss, if they are repeatedly exposed to excessive noise levels, usually above 85 decibels (dBA). Hearing loss differs from person to person and depends on the frequency of the noise, duration of exposure and employee behaviour (use of personal protective equipment (PPE).

I would like you to participate in this study. Refusal to participate will carry no penalty whatsoever.

Research process

- Prior to any engagement with research participants, ethical clearance will be obtained from the Human Research Ethics Committee (Medical) of the University of the Witwatersrand
- Your voluntary participation in the study is requested in the form of interviews and the wearing of a small and lightweight device called noise dosimeter over your shoulder for 8-hours a day for one day per campus, in order to measure personal noise levels
- The interviews and issuing of the noise dosimeters will be conducted by the researcher prior start of the work shift
- University management has given me permission to carry out this study
- The place for the interviews and issuing of the noise dosimeters will be at your workplace
- The researcher will take time to explain to the workers that the dosimeter only collects information on noise readings and that it does not record speech
- All the opinions and observations obtained during the study will be used to determine the overall perception of noise exposure risk

Photographic material

Photographs of the lawn maintenance machines and locations of the noise monitoring instruments will be required in order to give the reader of my report an idea of what type of machines were used during grass cutting activities and where the noise monitoring instruments were placed in relation to source and personal noise measurements. The photographs will be securely kept under lock and key on the researcher's personal computer, which is password protected. The photographs will not include faces of participants.

Confidentiality

In order to protect confidentiality of the participants, each worker will be given a unique study number and their names will be kept secret and only the number will be used throughout the research project. When the results of the study are presented, no names will be used. Identifiable information will be destroyed two years after the submission of the research report. The identity of the study site will be protected by refereeing to it as "Public University in

Gauteng”. Field data will be securely kept under lock and key on the researcher’s personal computer, which is password protected.

Withdrawal clause

Although your participation is important for this research project, your participation is voluntary and you have the right to withdraw from the study at any time with no harm coming you.

Study risks

Participation carries no known risk beyond your normal occupational hazards.

Potential benefits of the study

- The results may form a basis for policy formulation and implementation, to better allocate resources to enhance proper occupational health and safety governance, such as a hearing conservation programme in institutions of higher learning.
- The present knowledge gap - there is no existing database or hazard inventory - on lawn maintenance machines suggests the need to further explore or investigate this source of noise to determine its inherent risk to workers.
- Provide baseline data for the development of a hearing conservation programme and additional information to further understand the extent of noise exposure among groundskeepers. Such data may be useful in the establishment of the noise sources inventory, it could be used in health studies and may better inform epidemiological studies.

Cost

There is neither cost nor payment in being involved in the study.

Results

I will be happy to share a results summary with any study participant.

Contact details

If you have questions about the study, you may contact me, or my supervisor, using the details given below:

Principal Investigator: Mr Moses Mokone
Tel No.
E-mail address:

Supervisor: Dr Daniel Masekameni
Tel No.
E-mail address:

Ethics approval

This study has been approved by the Human Research Ethics Committee (Medical) of the University of the Witwatersrand, Johannesburg ("Committee"). A principal function of this Committee is to safeguard the rights and dignity of all human subjects who agree to participate in a research project and the integrity of the research.

If you have any concern over the way the study is being conducted, please contact the Chairperson of this Committee who is Dr Clement Penny, who may be contacted on telephone number 011 717 2301, or by e-mail on Clement.Penny@wits.ac.za. The telephone numbers for the Committee secretariat are 011 717 2700/1234 and the e-mail addresses are Zanele.Ndlovu@wits.ac.za and Rhulani.Mukansi@wits.ac.za

Thank you for reading this Study Information Sheet.

May 2021

7.4 Appendix D: Informed Consent

Study title: Occupational noise exposure among groundskeepers at a public university in Gauteng, South Africa

I hereby confirm that I have been adequately informed by the researcher about the nature, conducts and benefits of the study. I have also received, read and understood the above written information. I am aware that the results of this study will be anonymously processed into a research report. I understand that my participation is voluntary and that I may, at any stage, withdraw my consent and participation in this study, without any harm coming to me. I had sufficient opportunity to ask questions and of my own free will declare myself prepared to participate in this study.

Research participant's name:

____ (Please print)

Research participant's signature: _________________________________Date: ___________

Researcher's / data collectors name:

____ (Please print)

Researcher's / data collectors' signature: ______________________ Date: ____________

Researcher's contact details: Cell phone number E-mail address

079 346 4673 Mokonemoses@yahoo.com

7.5 Appendix E: Field Data Sheet

Study number **Date:**

____

A. Environmental conditions								
1. Instrument type and model		*2.* Instrument serial no.				*3.* External calibration Date		
4. Air temperature (◦C)	3.1 Morning reading		Time		3.2 Afternoon reading		Time	
5. Relative humidity (%)	4.1 Morning reading				4.2 Afternoon reading			

6. Wind speed (m/s)	5.1 Morning reading				5.2 Afternoon reading			
7. Description of the measurement environment: Clear sky? Windy? Cloudy? Wind direction? Dusty?								
B. Lawn maintenance equipment information								
8. Make			*9.* Total number of similar equipment					
10. Model								
11. Engine speed (rmp)		*12.* Sound power level (dB)						
13. Power source	13.1 Electric	13.2 Petrol	13.3 Diesel	*14.* Equipment age (yrs.)				

15. Maintenance history	15.1 Never serviced	15.2 Serviced periodically			
C. Sound level meter calibration data					
16. Acoustic calibrator type & model		*17.* External calibration date			
18. Pre-measurements		*19.* Post-measurements		*20.* Calibration deviation	
21. Calibrator dB output		*22.* Calibrator serial no.			
Internal calibration date					
D. Machinery noise measurements					
23. SLM type & model		*24.* Microphone serial no.			

<table>
<tr><td colspan="3">25. Measurement area</td><td colspan="7"></td></tr>
<tr><td colspan="3">26. SLM serial no.</td><td colspan="2"></td><td colspan="2">27. Activity area</td><td colspan="3"></td></tr>
<tr><td colspan="3">28. Measurement duration (Min)</td><td></td><td colspan="2">29. Time of measurement</td><td colspan="2"></td><td>30. Date of measurement</td><td></td></tr>
<tr><td colspan="2">31. Background noise (dBA)</td><td colspan="2">31.1 Machine-off</td><td colspan="2"></td><td>31.2 Machine-on</td><td></td><td>31.3 Difference (dBA)</td><td></td></tr>
<tr><td colspan="2">32. Type of noise</td><td colspan="2">32.1 Steady</td><td colspan="2">32.2 Fluctuating</td><td>32.3 Intermittent</td><td>32.4 Impulsive</td><td colspan="2">32.5 Cyclic</td></tr>
<tr><td rowspan="2">No.</td><td rowspan="2">Area/Location</td><td colspan="4">Measurement position (SPL/LAeq,T)</td><td colspan="2">Range (LAeq,T)</td><td>Average Noise Rating Level (LAeq,T)</td><td>Main noise sources</td></tr>
<tr><td>A</td><td>B</td><td>C</td><td>D</td><td>Min</td><td>Max</td><td></td><td></td></tr>
</table>

Description of the measurement area: Tasks performed? Machine operating condition? Machine demarcated? Grass cutting duration and frequency?

Controls in place? Grass condition – wet, dry? Secondary sources of noise?

E. Personal noise dosimeter calibration data

33. Acoustic calibrator type & model				*34.* External calibration date	
35. Pre-measurements		*36.* Post-measurements		*37.* Deviation	
38. Calibrator dB output		*39.* Calibrator serial no.			

<table>
<tr><td>40. Internal calibration date</td><td colspan="7"></td></tr>
<tr><td colspan="8">F. Personal noise measurements</td></tr>
<tr><td>41. Occupation/Job tittle</td><td colspan="2"></td><td>42. Shift duration (hrs)</td><td></td><td>43. Exposure duration</td><td colspan="2"></td></tr>
<tr><td>44. Measurement area</td><td colspan="7"></td></tr>
<tr><td>45. Similar exposure group</td><td></td><td>46. Activity area</td><td colspan="5"></td></tr>
<tr><td>47. Date of measurement</td><td></td><td>48. Start time</td><td></td><td>49. End time</td><td colspan="3"></td></tr>
<tr><td>Area/Location</td><td>LAeq, T</td><td>LAeq, 8-hour TWA</td><td>Peak (LCpk)</td><td colspan="4">Main noise sources</td></tr>
<tr><td></td><td></td><td></td><td></td><td colspan="4"></td></tr>
</table>

Description of the measurement area: Tasks performed? Machine operating condition? Machine demarcated? Grass cutting duration and frequency?

Controls in place? Grass condition – wet, dry? Secondary sources of noise?

7.6 **Appendix F: Questionnaire**

<table>
<tr><td colspan="8">A. General</td></tr>
<tr><td colspan="2">1. Department</td><td colspan="6"></td></tr>
<tr><td colspan="2">2. Monitoring area</td><td colspan="2"></td><td colspan="2">3. Shift duration (hours)</td><td colspan="2"></td></tr>
<tr><td colspan="2">4. Occupation/Job tittle</td><td colspan="2"></td><td colspan="2">5. Number of workers (SEG)</td><td colspan="2"></td></tr>
<tr><td>6. Age</td><td>18-25; 26-35,36-45; 46-55; > 56</td><td>7. Sex</td><td>Male; Female</td><td>8. Race</td><td colspan="3">Black; White; Coloured; Indian/Asian</td></tr>
<tr><td colspan="2">9. Home language</td><td colspan="2"></td><td colspan="2">10. Other (indicate)</td><td colspan="2"></td></tr>
<tr><td colspan="2">11. Years in current job</td><td colspan="2">1-5; 6 and above</td><td colspan="2">12. Education level</td><td colspan="2">Senior certificate, Diploma, Bachelor degree, Masters, Doctorate (PhD)</td></tr>
<tr><td colspan="8">B. Information and training</td></tr>
</table>

Topic/Question	Yes	No	Evidence
13. Have you ever received information and training on the effects of noise on hearing while working here?			
14. Do you know about the health effects of noise exposure?			
15. Were you trained on how to wear, use and care for your hearing protective devices (HDPs)?			
16. Have you been informed of the necessity and limitations of HPDs?			
17. Were you trained about the noise-rating limit and its meaning?			
C. Audiometric testing			
18. Do you experience any difficulties with your hearing?			
19. Have you ever been given a hearing test while working here?			

20. Do you perform leisure/recreational activities involving loud noise outside work?			
21. Before this work, did you work in any other noisy environment or in a job with exposure to noise?			
D. Noise measurements and exposure assessment			
22. Have you ever been monitored for noise exposure levels while working here?			
23. Do you have any concerns regarding noise in this workplace?			
24. Do you have Health and Safety Representatives in your workplace?			
E. Hearing protective devices (HPDs)			
25. Do you use hearing protective devices (HPDs) in your job?			
26. Did anyone explain why you need to wear HPDs?			

27. Does anyone check if you are wearing your HPDs?			
28. Do you store your HPDs after each use in a clean area?			
29. Do you routinely get new HDPs when it wears out?			
30. Are your HPDs comfortable when worn?			
31. Do you have any difficulty using your HPDs?			
32. Are you aware of a procedure for reporting and replacing defective HPDs?			
33. Do you think there is any value in wearing HPDs?			

7.7 Appendix G: Measured environmental conditions

Date	Air temperature (°C)	Relative humidity (%)	Wind speed (m/s)	Weather conditions
3/11/2021	24.5	15.3	0.65	Sunny and clear sky
3/11/2021	32.4	18.8	0.41	Sunny and clear sky
3/9/2021	22.4	25.9	1.12	Sunny and clear sky
3/9/2021	19.6	37	1.37	Sunny and clear sky
4/11/2021	25.7	37.1	1.03	Sunny and clear sky
4/11/2021	26.3	29.2	0.87	Sunny and clear sky
1/9/2021	21.8	17.7	0.75	Sunny and clear sky
1/9/2021	24.7	15.2	1.16	Sunny and clear sky
2/9/2021	22.9	22.2	1.15	Sunny and clear sky
2/9/2021	22.5	24.8	1.07	Sunny and clear sky