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Noise-induced hearing loss: Prevalence, degree and impairment criteria in South African gold miners

by

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Abstract

Despite the preventability of noise-induced hearing loss (NIHL) a high prevalence is still reported in South African mines. The study aimed to describe the hearing of gold miners pertaining to the prevalence and degree of NIHL and effectiveness of current RSA impairment criteria to identify NIHL.

The audiological data, collected between 2001 and 2008, of 57 714 mine workers were investigated in this retrospective cohort study. Data was accessed through the mine's electronic database and exported to Microsoft Excel 2007 worksheets. Participants were categorised in terms of noise exposure (level and working years), age, race and gender. Noise exposure levels were described in terms of a specific occupation and categorized into four groups based on dosimeter data received from the mine's noise hygienist, namely: 1) Below surface (underground) noise exposure, ≥85 dB A, classified according to the South African regulations on the daily permissible dose of noise exposure[8], named Noise Group 1; 2) Surface noise exposure, ≥85 dB A, named Noise Group 2; 3) No known occupational noise exposure, named control group; and 4) Uncertain levels of noise exposure, e.g. students and trainees, named Noise Group 4. The control group was matched with participants of noise group 1 and 2 based on gender, race and age at the most recent audiogram test. Descriptive and inferential statistics were employed. Measures of central tendency and variability were used with analysis of covariance (ANCOVA) and pairwise comparisons according to Fisher's Least Squares Differences Approach (F test).

Results indicated that noise exposed groups had significantly higher prevalence of high and low frequency hearing loss than the control group. High-frequency hearing loss was also present in the control group. The greatest differences in prevalence of hearing loss were observed at 3, 4 kHz and age group 36 to 45 years. Thresholds at 8 kHz were worse than expected and decline slowed down with age. High-frequency thresholds showed a non-linear growth pattern with age with a greater decline at 2 kHz with age in the noise-exposed population compared to the control group. Hearing deteriorated more across age groups with more noise-exposed years, and this deterioration was most visible after 10 to 15 working years and at 3 kHz. Females had better hearing than males across the frequency spectrum. Black males had significantly better high-frequency hearing than white males but significantly worse low-frequency hearing than white male counterparts. PLH values showed poor correlation (through statistical analyses) with other well-accepted hearing impairment criteria.

To date this was the largest study conducted on the hearing of gold miners and the sample included a very large number of black males exposed to occupational noise (N=17 933). Values supplied in distribution table format are therefore unique and contribute greatly to the knowledge base.

Key terms:

Noise-induced hearing loss

Gold mines

Occupational noise

Percentage loss of hearing

Race

Gender

Age related hearing loss

Noise exposure

Prevalence

Degree of hearing loss

Notch

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List of Acronyms

AMA	American Medical Association
ANSI	American National Standards
ARHL	Age related hearing loss
ASHA	American Speech and Hearing Association
COIDA	Compensation for Occupational Injuries and Diseases Act, No. 130 of 1993. South Africa
dB A	Decibel A-weighted
dB HL	Decibel hearing level
dB SPL	Decibel sound pressure level
DPOAE	Distortion Product Otoacoustic Emmission
HCP	Hearing conservation programme
HEG	Homogenous exposure group
ISO	International Organization for Standardization
kHz	Kilohertz
MHSC	Mine Health and Safety Council
NIHL	Noise-induced hearing loss
NIOSH	US National Institute for Occupational Safety and Health
OAE	Otoacoustic Emmission
OEL	Occupational exposure level
OSHA	The United States Occupational Safety and Health Administration
PLH	Percentage loss of hearing
PTA346	Pure tone average of 3, 4 and 6 kHz
PTA512	Pure tone average of 0.5, 1 and 2 kHz
RSA	Republic of South Africa
SANS	South African National Standards
SANS 10083: 2007	SANS: The measurement and assessment of occupational noise for hearing conservation purposes
TWA	Time weighted average
WHO	World Health Organization

Chapter one INTRODUCTION AND RATIONAL

1. Noise-induced hearing loss: Prevalence, degree of hearing loss and impairment criteria in South African gold miners

1.1. Introduction and study rational

Noise-induced hearing loss is no new phenomenon but the last two centuries has seen a significant increase in its occurrence. This can be attributed to the industrial revolution which saw the increase of mechanical equipment capable of producing hazardously loud noise and the widespread availability of gunpowder. It was noise-induced hearing loss (NIHL) which “gave birth” to the profession of Audiology in the 1940s when soldiers returned from World War II with acquired hearing loss caused by gunfire and explosions (Clark, 2000). Today it is estimated that over one-third of the 28 million Americans who have some degree of hearing loss, were affected, at least partly, by noise (American Speech-Language-Hearing Association (ASHA, 2007). Excessive noise exposure is also prevalent in developing countries, such as Africa, in the formal (e.g. mining and construction) and informal occupational sector (e.g. vehicle repair) as well as the non-occupational sector (urban, environmental and leisure) (World Health Organization (WHO), 1997). The WHO estimates that 18% of adult-onset hearing losses in the 20 southern most countries in Africa (AFR-E region), including South Africa, might be due to NIHL in the workplace (Nelson et al., 2005b).

Noise can be defined as unwanted sounds that have the potential to interfere with communication or damage people’s hearing (Franz & Phillips, 2001). Noise exposure levels related to an 8-hour working day (LEx,8h), exceeding the occupational exposure limit (OEL) of 85 dB A[1], are considered to be dangerous to the auditory system (Plontke, Zenner & Tübingen, 2004; Franz & Phillips, 2001). Excessive noise, at this limit or exceeding it, can irreversibly damage sensory hair cells of the cochlea. This results in a progressive, sensorineural, hearing loss that is predominantly noted in the high frequency region with a typical notch at 4 kHz (Śliwinska-Kowalska, Dudarerewicz, Kotył0, Zamysłowska-Szmytke, Wlaczyk-

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[1] Sounds at some frequencies are more hazardous than at other frequencies. The use of A-weighted sound levels cancels these effects, so that two sounds with the same dB A level have approximately the same hazard (Dobie, 2001).

Łuszczyńska, Gadja-Szadkowska, 2006; McBride & Williams, 2001; Rabinowitz, Galusha, Slade, Dixon-Ernst, Sircar, & Dobie, 2006 & May, 2000). Significant individual variability in susceptibility to NIHL is evident and may be due to many factors including a history of exposure to noise, previous treatment with ototoxic drugs, exposure to organic solvents, long-term smoking, gender, pigmentation, age and genetic make-up (Perez, Freeman & Sohmer, 2004; Agrawal, Niparko, Dobie, 2010). Despite the variability in susceptibility to NIHL, no one is immune to the devastating effect of loud noise over a prolonged period of time. The result is a disabling condition which negatively affects a person's ability to communicate and interact socially with detrimental effects on work performance (Passchier-Vermeer & Passchier, 2000).

In the 1940s the treatment of NIHL was accentuated, but since then the emphasis has shifted from treatment to prevention. NIHL is now recognised as a preventable health effect of excessive noise in the workplace (Nelson, Nelson, Concha-Barrientos, & Fingerhut, 2005a). In the interest of prevention noise exposure in the workplace should be investigated. Review of the literature reveals that information on the level of noise exposure in the workplace is not readily available internationally. In this regard a WHO review to determine the global burden of occupationally induced NIHL stated that summary statistics on noise exposure are not available for most industrialising and non-industrialised countries (Nelson, et al., 2005a). In search for information on occupational noise exposure levels the researchers reviewed 17 studies conducted in 12 countries in South America, Africa, and Asia. The review reported on high occupational noise exposure levels (85 dB A or more) and associated hearing loss which occurred in a wide range of workplaces, including manufacturers of foods, fabrics, printed materials, metal products, drugs, watches, and in mining. Based on United States of America (USA) data the researchers estimated the proportion of workers in each occupational category with exposure to noise at or above 85 dB A in nine economic sectors. The industry with the highest estimated value was mining with an estimated 0,85 of all the production workers and labourers exposed to noise levels at or above 85 dB A (Nelson, et al., 2005a).

In South Africa mining is the country's largest industry employing 5,1% of all workers in the non-agricultural, formal sectors of the economy, a reported total of 458 600 employees in 2006 (Mwape, Roberts, & Mokwena, 2007). The processes associated with mining generate tremendous noise as a result of activities including percussion drilling, blasting and crushing of ore which is often exacerbated by confined and reflective spaces (MHSC[2], 2005). The results of a recent study investigating the profiles of noise exposure in South African mines indicate that the mean noise exposure levels in the South African mining industry range from 63.9 dB A to 113.5 dB A and that approximately 73.2 per cent of miners in the industry are exposed to noise levels of above the legislated OEL of 85 dB A (Edwards, Dekker, & Franz, 2011). In a recent study by (Phillips, Heyns, & Nelson, 2007), commissioned by the MHSC) the noise and vibration levels recorded during the operation of three types of rock drills currently used in the mining industry were compared. The researchers concluded that typical noise levels on conventional equipment are still exceeding the occupational exposure limit.

Despite the fact that NIHL is preventable and that the South African mining industry introduced hearing conservation programmes (HCP) in 1988 (Chamber of Mines Research Organisation (COMRO), 1988) a high prevalence of NIHL is still reported in South African mines (MHSC, 2007, Hermanus, 2007). Because occupational NIHL is a significant source of potentially avoidable morbidity it has been categorised as a compensable disease in South Africa in terms of Schedule three of the Compensation for Occupational Injuries and Diseases Act 1993 (COIDA, 1993). The present situation regarding compensation of this occupational disease reportedly does not reflect the exposure or burden of disease, but could be used to indicate the severity of the risk (SIMRAC, 2003). It is reported that 3 849 new cases of NIHL were submitted to the South African Mining Occupational Disease Database (SAMODD) in 2004 and compensation to the amount of ZAR 77 067 521 was paid (MHSC, 2007). An audit of the Department of Minerals and Energy in the RSA reported 1820 cases of NIHL in 2007 (as identified by medical evaluations) (Sonjica & Nogxina, 2008). It is possible that reported NIHL cases could have been inflated soon after 2001 as baseline hearing testing was only mandated after 2001. Since then a positive downward trend in the number of NIHL cases has been reported by the Chamber of Mines (since the baseline as per Instruction 171 in 2002/2003 (Chamber of Mines, 2012)). The current rate (2011) of NIHL is at 3.1 cases per 1

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[2] A schematic representation of the structure and mandate of the Mine Health and Safety Council (MHSC) is included as appendix B.

000 employees. It has been stated however that the number of compensable cases will rise again in future when the threshold for compensable hearing loss is breached (Hermanus, 2007). In 2005 NIHL was reported to be responsible for ±15% of all occupational disease claims submitted to the Rand Mutual Assurance Company (RMA) who underwrites workers' compensation benefits for the mining industry in South Africa. Furthermore NIHL accounted for almost half of the compensation benefits paid out to claimants in 2005 (RMA, 2005).

In view of the high prevalence of NIHL in the mining industry the MHSC comprising representatives of state, labour and employers, signed an agreement with the mining industry in 2005 to achieve two important milestones (MHSC, 2005). Firstly, it was agreed that after December 2008, the hearing conservation programme implemented by industry must ensure that there is no deterioration in hearing greater than 10%[3] amongst occupationally exposed individuals. Secondly, parties consented that by December 2013, the total noise emitted by all equipment installed in any workplace must not exceed a sound pressure level of 110 dB A at any location in that workplace (including individual pieces of equipment). Achieving these targets is an important and significant challenge which the MHSC will reportedly continue to facilitate through its advisory function (MHSC, 2006). The difficulty in defining and calculating reliable incidence and prevalence data remains a major challenge and should be a main focus area within occupational health research according to the MHSC (2006). An evaluation of the current status of NIHL prevention practices in the small- to medium mining sector was performed in light of these milestones and results indicated that unless interventions occur the possibility of achieving the 2013 milestone is very poor (Dekker, Edwards, Franz, van Dyk, & Banyini, 2011)

Nowhere are these targets more of a priority than in South African gold mines which are a central part of the national mining industry. The first recording of a gold discovery during the modern era in South Africa was more than a century ago in 1871 (Conradie, 2007). Much has changed since then: in 2006 forty seven of South Africa’s 1 212 mines and quarries produced gold, and a total of 159 984 people were employed in gold mines in that year (out of the total of 458 600 employed in the

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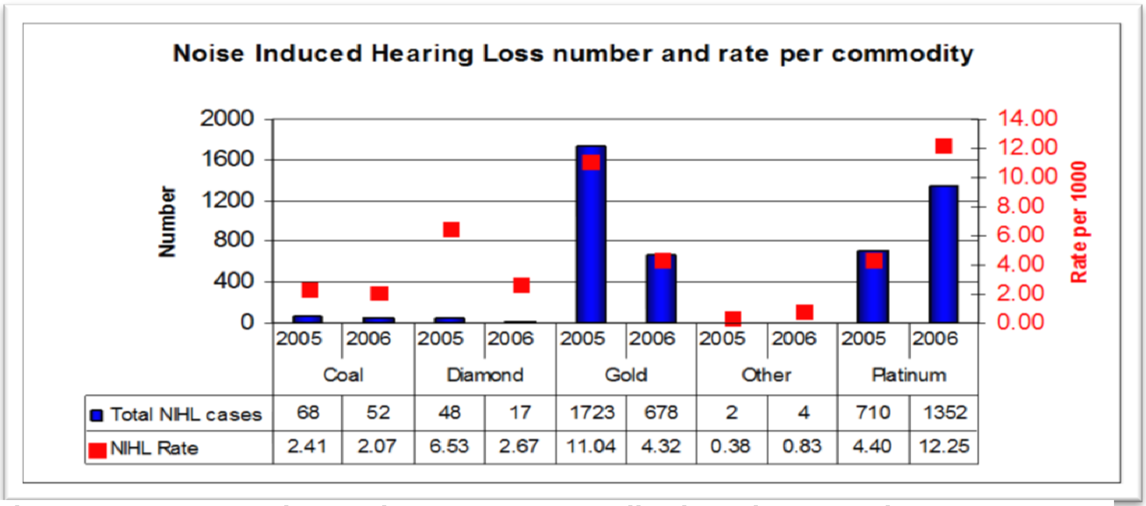
[3] This refers to a shift in percentage loss of hearing (PLH) from the baseline audiogram or a 10% PLH for employees for whom no baseline audiogram is available. More information on this procedure follows on page eight, paragraph two of this document.

mining sector) (Mwape, et al., 2007; Conradie, 2007). The gold mine industry, as a major employer in the mining sector, has committed to the targets and milestones agreed to by the MHSC (AngloGoldAshanti, 2007; Department of Minerals and Energy, 1996).

In order to define prevalence and incidence data of NIHL in South African mines annual reports and statistical analyses of South African data provide valuable information. Reports from the South African Chamber of Mines and the MHSC describe a particularly high incidence of NIHL in gold miners (Chamber of Mines, 2009; DME, 2003) . Figure 1.1 demonstrates a prevalence rate of 11,04 per 1 000 workers with reported NIHL in 2005 and 4,32 per 1 000 workers in 2006 in South African gold mines.



	Coal		Diamond		Gold		Other		Platinum	
	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006
🟦 Total NIHL cases	68	52	48	17	1723	678	2	4	710	1352
🟥 NIHL Rate	2.41	2.07	6.53	2.67	11.04	4.32	0.38	0.83	4.40	12.25

Figure 1-1 NIHL number and rate per commodity (Randera, 2007)

Apart from annual reports available from specific mining groups (e.g. AngloGold Ashanti), the MHSC and the Chamber of Mines very few research reports relating to NIHL in South African mines are available in current literature. Some recent studies described the utility value of certain audiological tests as part of the battery of hearing tests (De Koker, 2003), and the prediction of hearing handicap through utilisation of the audiogram configuration and a self-report handicap scale for a group of gold miners (n=339) (Vermaas, Edwards, & Soer, 2007). Another South African study described the characteristics of NIHL in gold miners of different ages and occupation types of a group of gold miners (Soer, et al., 2002). Because of relatively small sample sizes and the sampling methods (convenience sampling) these studies do not describe the prevalence of NIHL in the gold mines.

A survey study reporting on NIHL in South African gold miners completed two decades ago describes the hearing status and noise exposure of 2 667 white gold miners (Hessel & Sluis-Cremer, 1987). Although this study was not representative of the gold mining community since no black miners were included (the majority of gold miners are black (Conradie, 2007)) results from this study has been used in other prevalence studies (Nelson, et al., 2005a). For this study hearing impairment was defined as an average loss of >25 dB HL for the audiometric frequencies 0,5, 1 and 2 kHz, with five times weighting of the better ear. At age 58, 21,6% of gold miners fell in this group.

Since the Hessel & Sluis-Cremer (1987) study much has changed in the industry in terms of the legal diagnostic criteria for NIHL. A new procedure for identifying and evaluating cases of NIHL for compensation was introduced in 2001 in a guideline issued by the Compensation Commissioner, Instruction 171 (COIDA, 2001). An important change from the previous procedure is the use of a working lifetime baseline audiogram to calculate whether compensation should be provided. When a baseline audiogram is available only the deterioration from the baseline is used to calculate disablement. Instruction 171 introduced a measure of impairment termed percentage loss of hearing (PLH) which is calculated by using a series of tables based on a summation of hearing loss in each ear at the following frequencies: 500, 1 000, 2 000, 3 000 and 4 000 Hz (COIDA, 2001). Circular Instruction No. 171 of the Compensation for Occupational Injuries and Diseases Act, No. 130 of 1993 (2001) is included as Appendix C.

Because of the different ways in which hearing impairment is defined in South African mines after 2001 and prior to 2001, it is difficult to get a clear picture of or compare results on the prevalence of NIHL in mine workers. This is not only true of South African research but controversies regarding the method or measures used to estimate hearing impairment abound internationally (Dobie, 2001). When calculating hearing impairment using pure tones many questions arise relating to the frequencies that should be included. These questions include the level at which impairment begins (the low fence), the level of total impairment (high fence), the linearity of hearing impairment with increasing impairment, and finally questions relating to the weighting of the better and the worse ear (Dobie, 2001). The following figure demonstrates the audiogram (dB HL) of a typical NIHL. Table one compares the hearing impairment measured as percentage of hearing impairment for a typical noise-induced hearing loss for different criteria described in the current literature to illustrate the discrepancy between methods.

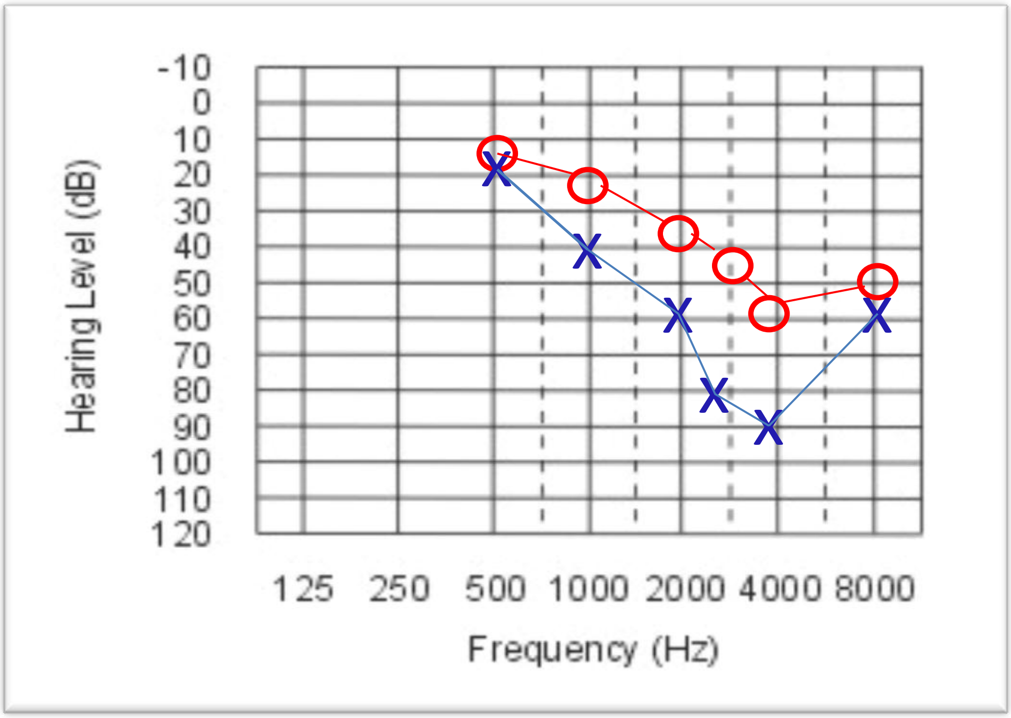


Figure 1-2 Audiogram for a typical NIHL (values based on an illustration by Dobie (2001)

Table 1-1A comparison of the calculated "percentage of hearing impairment" using different criteria for the audiogram shown in figure 2

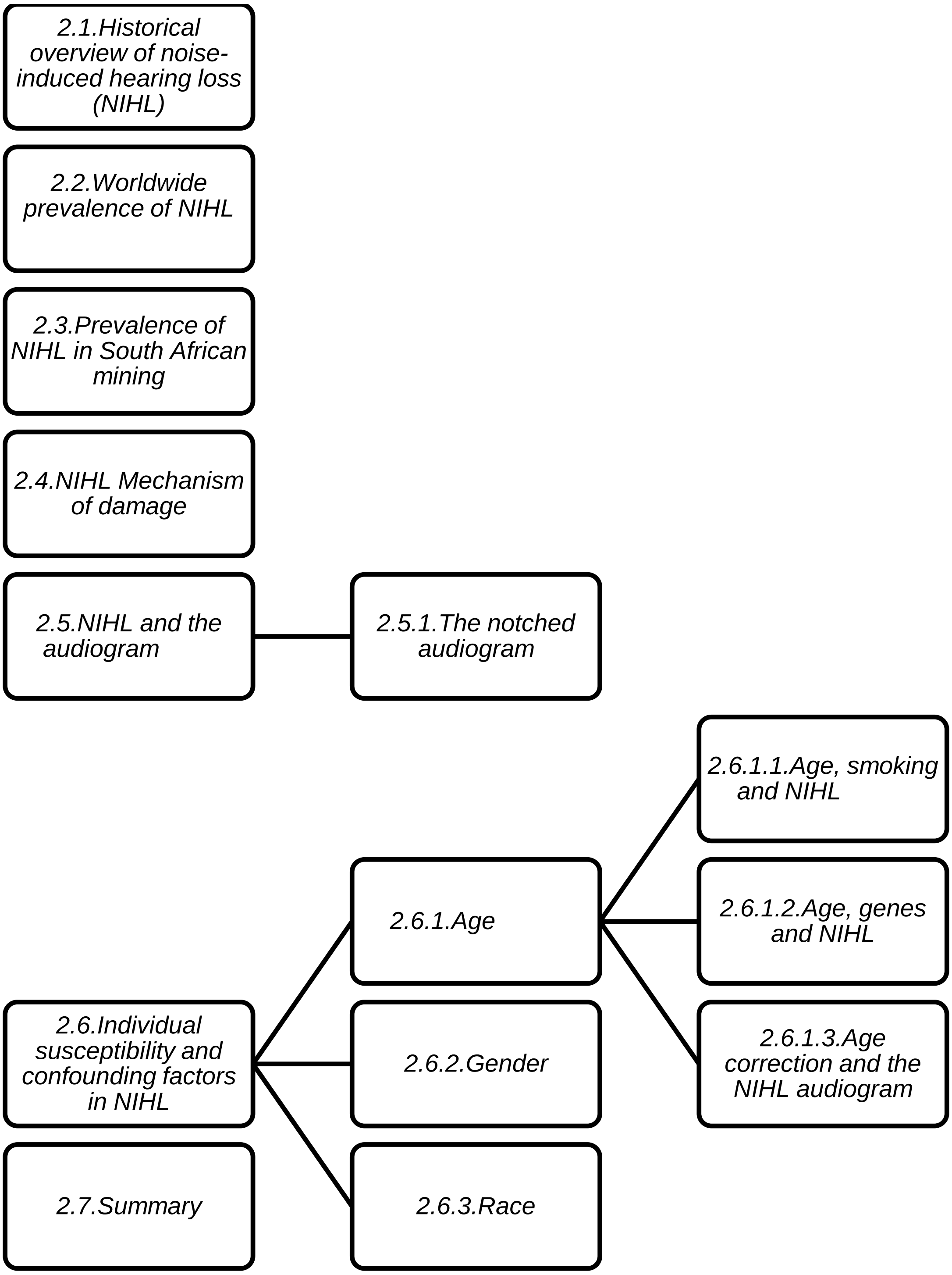
Method	Frequencies averaged (kHz)	Hearing Impairment/ PLH (%)
AMA (2000)	0,5, 1, 2, 3	12,5%
US Department of Labor (2000)	1, 2, 3	21,.25%
ASHA (2000)	1, 2, 3, 4	41,25%
Instruction 171 (RSA Department of Labour, 2000, COIDA, 2001)	0.5, 1, 2, 3, 4 (using weighted calculation tables)	24,3

Source: American Medical Association (AMA; 2000), U.S Department of Labor (Dobie, 2001), American Speech and Hearing Association (ASHA) (Dobie, 2001) and Instruction 171 (COIDA, 2001).

From table one it is clear that the percentage of hearing impairment is very different depending on the criteria for calculating hearing impairment employed. Apart from calculation with Instruction 171, the other methods use a five: one favouring the better ear, and a 25dB HL low fence (Dobie, 2001). The ASHA method uses a two percent growth rate (with the high fence at 75 dB HL) while the other methods (Instruction 171 excluded) use a 1,5% and a 92 dB HL high fence (ASHA, 2004; Dobie, 2001). The methods using high frequencies result in a larger estimate of hearing impairment for typical cases of NIHL (or any other high frequency hearing loss). In the summation used for calculation of the PLH according to Instruction 171 the weighting of hearing loss varies from frequency to frequency. The weighting is highest for hearing loss at a frequency of 1 kHz and lowest for hearing loss at a frequency of 4 kHz (Franz & Phillips, 2001). This is contrary to what one expects as NIHL is often characterised by the "notch" in the audiogram at 4 kHz or a high frequency hearing loss (Rabinowitz, et al., 2006). This brings into question a final controversy regarding the calculation of hearing impairment percentage that is often ignored and that relates to the cause of the hearing loss and the audiometric configuration (Dobie, 2001). For example, noise and aging often interacts and it has been argued that calculation of hearing impairment should include an allowance for the hearing loss expected with advancing age (Davis, 1971 & Dobie, 2001).

Taking into account the many controversies surrounding the calculation of hearing impairment, the dearth of research describing NIHL and the rate of hearing threshold deterioration in the mining community of South Africa, the following research question was posed: What is the prevalence and degree of NIHL in a group of gold miners and is current criteria for characterising hearing impairment in South Africa valid for identifying NIHL in gold miners?

2. Noise-induced hearing loss: Overview



The following scheme outlines the literature review that was followed in Chapter 2 and 3:

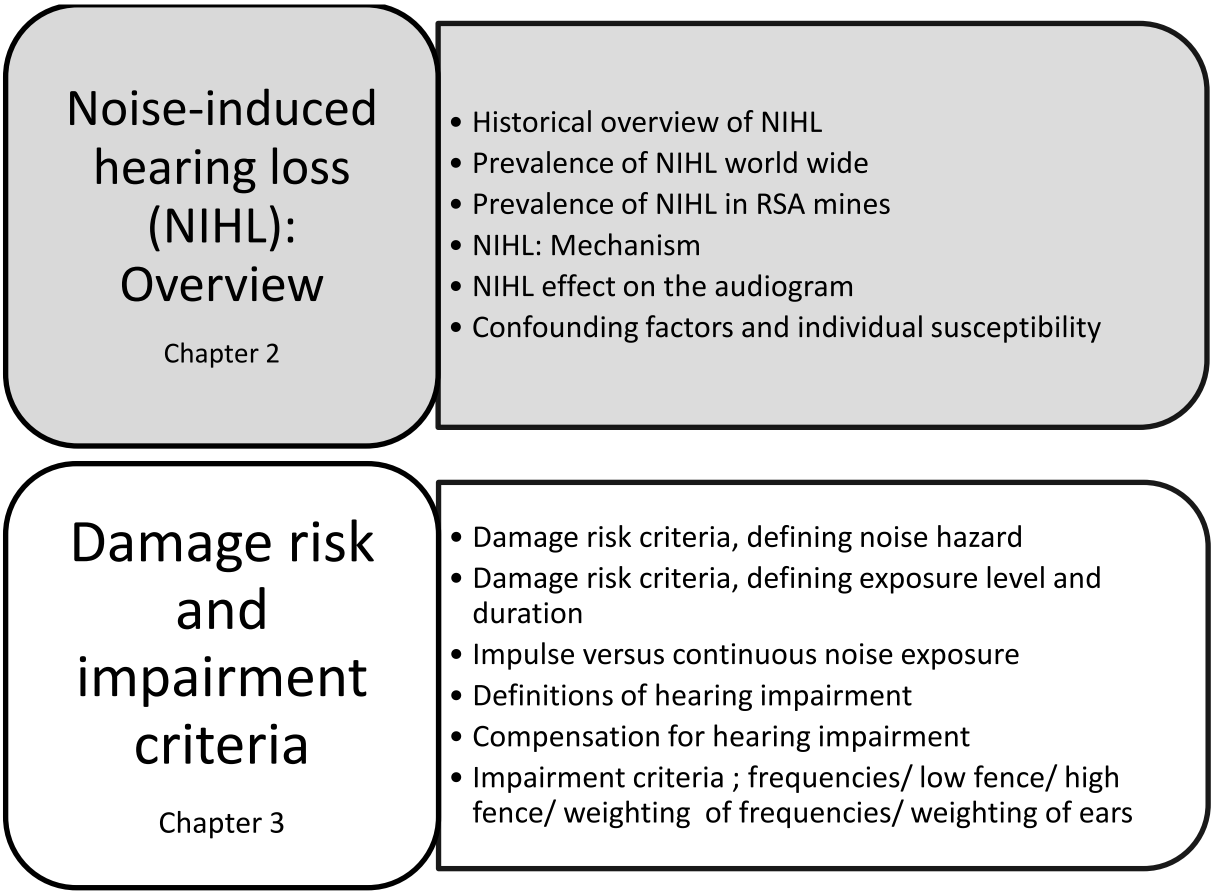


Figure 2-1 Outline of literature review followed in chapters two and three

2.1. Historical overview of noise-induced hearing loss (NIHL)

For the audiologist hearing loss caused by noise has a special significance as the profession of audiology owes its origin to hearing loss caused by war-related blasts and gunfire (Clark, 2000). Excessive noise has always been associated with firearms, ammunition and wars. Centuries ago noise-induced hearing loss (NIHL) was first documented by a French surgeon, Ambroise Paré (1510-1590), when he described the treatment of injuries sustained by firearms (Mcllwain, Gates, & Ciliax, 2008). According to the medical records of United States Army (USA) (Mcllwain, Gates, & Ciliax, 2008) many soldiers were diagnosed with hearing loss after World War I. It was only after the Second World War in 1945, however, that the profession of audiology was born to address the great need for intervention after many soldiers had sustained hearing loss. After this life-altering war, the terms “audiology” and “audiologist” were used for the first time (Berger, 1976; Jerger, 2009).

Loud noise, however, is not only associated with wars and ammunition. As the effects of the Industrial Revolution spread throughout Western Europe and North America during the 19th century many changes were made to methods of work by the introduction of machinery (Deanne, 2000). Hazardous noise in the workplace was an inevitable consequence. The introduction of steam power relating to the industrial revolution first brought attention to noise as an occupational hazard (NIOSH, 1998). Craftsmen who fabricated steam boilers developed hearing loss in such numbers that the resultant impairment was referred to as “boilermaker’s disease” (Clark, 2000; NIOSH, 1998). The recognition of “boilermaker's disease” has been referred to in literature as one of the major historical events in the relating of noise-induced hearing loss to noise exposure (Johnson, 1999). The devastating effect of noise on hearing has since multiplied in most trades and all industries as a result of increasing mechanisation.

Mining is yet another trade strongly associated with excessive noise. Mining minerals has always been a gruelling, forceful task both underground and on the surface. As early as the first century BC Diodorius Siculus (Greek historian; 1st century BC (Agricola, 1950)) describes the process of mining: *“The physically strongest break the rock with iron hammers, applying no skill to the task, but only force”* (Agricola, 1950, p. 280). Drilling shot holes was one of the first mining operations to become mechanised (McBride, 2004). Today the pneumatic percussion drill is still regarded as one of the major noise hazards in mining (McBride, 2004).

In the early years audiologists focused mainly on the treatment of NIHL. Since then the focus has shifted from intervention to prevention of NIHL. Although the measurement of hearing loss was possible prior to 1940 it was not until 1937 that actual reports of hearing measurements were made of persons with NIHL (Glorig, 1980). A group in the Armed Forces of the USA gave research momentum when a working group was formed in 1953 to study the effects of high intensity noise on the human body (McIlwain, Gates, & Ciliax, 2008). This study was called the Biological Effects of Noise Exploratory Study (BENOX Report) and it became the first report to recommend monitoring for the prevention of NIHL as well as the establishment of a database to track hearing loss (Johnson, 1999; Mcllwain, Gates, & Ciliax, 2008). As a result of the BENOX Report and the wide distribution of its results, prevention was considered the best solution to noise-induced hearing loss.

The American Academy of Otology and Otolaryngology published the first written guide on hearing conservation outside of the military in 1953. Hearing conservation can be defined in a broad sense as the preservation of normal and residual hearing (Glorig, 1980). In the United States the federal government included a noise standard in the Occupational Health and Safety Act of 1972 (Sataloff & Sataloff, 2006). This standard made it mandatory for industries to reduce noise by every feasible means where employees are exposed to harmful noise. If the noise cannot be reduced adequately a hearing conservation programme has to be established. In 1979 the US Department of Labor regulated the elements of a hearing conservation programme which included guidelines and forced industrial compliance (Sataloff & Sataloff, 2006).

The shifting of the focus to prevention of NIHL through regulations and hearing conservation programmes soon spread from the United States to other countries around the globe. In the United Kingdom a joint investigation by the Medical Research Council and the National Physical Laboratory established the relationship between noise exposure and hearing loss and defined data regarding noise levels and duration of noise exposure with consequent hearing loss (Flood, 1987). The results from these studies led to a Code of Practice published by the Department of Employment (UK) in 1972. Although this code was an advisory document, a breach of this code was admissible as evidence of negligence and breach of statutory duty (Uddin, Dingle, Sharp, & Flood, 2006).

In 1981 the Occupational Safety and Health Association (OSHA[4]), who is the main US federal agency charged with the enforcement of safety and health legislation, created hearing conservation standards for employees exposed to excessive noise (US Department of Labor, 1983). The standards specified the permissible sound levels and duration of noise exposure and also mandated hearing conservation

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[4] OSHA: The United States Occupational Safety and Health Administration (OSHA) is an agency of the United States Department of Labor with the mission to prevent work-related injuries, illnesses, and occupational fatality by issuing and enforcing standards for workplace safety and health (retrieved from http://www.osha.gov/comp-links.html on March 08, 2011).

programmes (HCP) for workers exposed to excessive noise (US Department of Labor, 1983).

Shortly thereafter NIHL in South African gold miners was reported in the medical literature (Hessel & Sluis-Cremer, 1987). In 1988, soon after this publication, the South African Chamber of Mines published guidelines for the implementation and control of an HCP in the mining industry (COMRO, 1988). In 1996 the components of HCPs were included in the Mine Health and Safety Act (Department of Minerals and Energy, 1996).

2.2. Worldwide prevalence of NIHL

Even with the shift in emphasis from treatment to prevention and the worldwide implementation of hearing conservation programmes, hearing loss caused by noise is still prevalent (SANS10083:2004, 2004). A study commissioned by the World Health Organisation (WHO) evaluated the worldwide status quo of occupational noise exposure and resultant hearing loss (Nelson, et al., 2005a). This comparative risk assessment was done as part of the WHO's on going Global Burden of Disease (GBD)[5] project.

The assessment estimates the global burden[6] of disease and injuries resulting from risk factors including NIHL (Nelson, et al., 2005). According to this study, the WHO estimates indicate that a large percentage of disabling hearing loss in adults worldwide is attributable to occupational noise (Nelson, et al., 2005a). Nelson and colleagues (2005) give account of 17 studies conducted in 12 countries where high occupational noise exposure levels were reported. These high noise levels occurred

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[5] The WHO GBD measures burden of disease using the disability-adjusted life year (DALY). This time-based measure combines years of life lost due to time lived in states of less than full health. The DALY metric was developed in the original GBD 1990 study to assess the burden of disease consistently across diseases, risk factors, and regions. In summary the GBD provides estimates of mortality and morbidity for causes of disease and injury (WHO, Global Burden of Disease, 2009).

[6] The term "burden" is a term typically used by population studies to refer to the effects of hearing loss. These effects, primarily on speech communication, and secondarily on social, emotional, and other domains of functioning, have often been subsumed under terms such as handicap, impairment, and disability (Dobie, 2008).

in a wide range of workplaces, including manufacturers of foods, fabrics, printed materials, metal products, drugs, watches, and in mining. Using noise exposure data from the US National Institute for Occupational Safety and Health (NIOSH), adjusted by data on the distribution of the workforce by occupational category and economic sector, and economic activity rates in each WHO subregion, the results indicated that occupational noise is an important risk factor for hearing loss in workers at most ages. Prevalence of NIHL range from 7% to 21% (averaging 16%) of the adult-onset hearing loss around the world (Nelson, et al., 2005a). Results indicate that the burden is more profound for certain occupations such as mining, and for males compared to females. Furthermore the burden is more significant in the developing world. It is estimated that 18% of adult-onset hearing losses in the 20 southern most countries in Africa (AFR-E region), including South Africa, are due to occupational noise exposure (Nelson, et al., 2005a).

Dobie (2008) provided a critical appraisal of the WHO study (Nelson, et al., 2005a). Dobie (2008) was part of a study estimating the contribution of aging and noise as causes of adult-onset hearing loss in the United States. The author questioned methodological aspects related to the WHO study (Nelson, et al., 2005a). In the risk assessments, for example, different hearing loss definitions were combined in a single model and age weighting was used. In this study a model of the hearing loss burden in American adults was constructed using data from the Census Bureau, from an international standard that predicts age-related and noise-induced hearing loss (ISO 1990:1999), from the American Medical Association's method of determining hearing impairment, and from sources estimating the distribution of occupational noise exposure in different age and sex groups (Dobie, 2008). Despite the differences in methodology, results from both studies estimate a similar burden of occupational NIHL. Dobie (2008) estimated that 10,5% of adults with moderate hearing loss in North America may be attributed to occupational noise, very similar to the WHO estimate of 9%. Results from both studies revealed that the risk peaked in middle age (45 to 59) (Dobie, 2008; Nelson, et al., 2005a). Regarding the higher WHO estimate for the burden of NIHL in developing countries (such as South Africa, 18%) versus developed countries (North America, 9%) Dobie and colleagues argue that these results can be supported by the fact that as manufacturing leaves countries like the United States, developing countries have an *“ever-increasing share of the world’s noisy jobs”* (Dobie, 2008, p. 574).

Both these studies thus confirm that a large proportion of adult-onset hearing loss can be attributed to occupational noise. Some factors might lead to an underestimate of the burden of NIHL. Prevalence studies in occupational diseases, such as NIHL, might for example be hampered by the fact that there is often an extended lead time for the disease to develop (Scott, Grayson, & Metz, 2004). If hearing is not tested frequently, NIHL might be underreported as figure 1 demonstrates. Due to this latency period of many occupational diseases, symptoms often present after a worker had left a workplace and thus go unidentified (Hermanus, 2006).

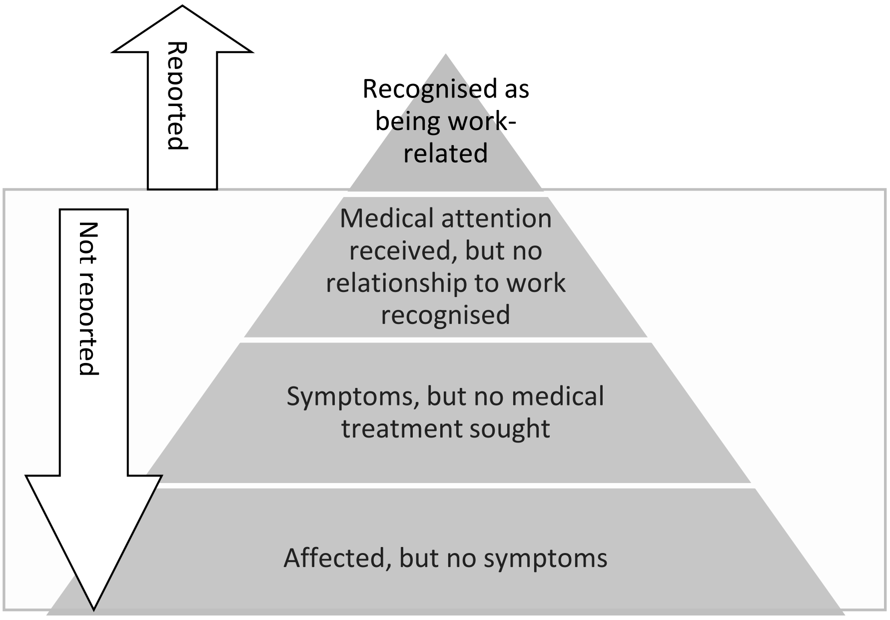

Figure 2-2 Underreporting of occupational diseases. Source: Scott, Grayson, & Metz (2004)

2.3. Prevalence of NIHL in South African mining

Mining as an occupation was identified in the WHO GBD study as an economic sector with a heavy burden of NIHL (Nelson, et al., 2005a). South Africa has a particularly large share of “noisy jobs” since the country has a large mining industry. The South African mining industry employs 5,1% of all workers in the non-agricultural, formal sectors of the economy, a reported total of 458 600 employees in

2006 (Mwape, et al., 2007). Results from a population- based study done by the National Institute of Occupational Safety and Health (NIOSH, 1998), referenced by Nelson and colleagues, indicate that 85% of all production workers and labourers in mining (in the US) were exposed to excessive noise. A recent survey of noise in South African mines found exposure values for operators of production machinery and for personnel in close proximity to range between 95 and 110 dB A (Franz & Phillips, 2001). It is estimated that 68 to 80% of mineworkers are exposed to dangerous noise levels, indicating a significant risk of hearing loss for the majority of the industry's personnel (Franz & Phillips, 2001).

A literature search reveals that no large scale prevalence studies have been conducted on NIHL in the mining industry in South Africa. The bulk of published material has been in the form of case reports, pathology studies, and collections of statutory data with few prevalence or incidence studies. The data used in the WHO burden of disease study was collected by Hessel and Sluis-Cremer (1987). The hearing loss of a large cohort of white gold miners, who constitute a very small section of the workforce in the mining industry, were investigated. In a frank and revealing article by McCulloch (2005) about the history of South African research into occupational diseases it is described as tainted by political agendas. In the article the author describes how research into the devastating effects of asbestos was stifled because of fear that it might negatively impact the prosperous industry. According to the author, South African science in this area was rendered irrelevant on the international stage because of unethical research practices which also reflect on how the industry managed occupational and environmental diseases (McCulloch, 2005). Ironically the author describes how researchers working at the National Institute for Occupational Health (NCOH) in South Africa between 1970 and 1990, including Sluis-Cremer, who co-authored a landmark NIHL study (Hessel & Sluis-Cremer, 1987), eventually died because of asbestos poisoning after only a few visits to these mines despite scientific claims to the safety of mining practices (McCulloch, 2005). The impact of many discriminatory practices of South Africa's past, which were allowed by legislation, such as disproportionate compensation pay-outs and benefits to black and white miners, inferior housing, poor working conditions and a general neglect of health and safety, is still evident and unfolding (Hermanus, 2006).

The Leon Commission of Inquiry of 1994 is the most recent commission to examine occupational health and safety in the South African mining industry (Franz & Phillips, 2001). In terms of occupational health, and specifically NIHL, the Commission found that between 40 to 80% of workers involved in drilling operations have hearing loss after 10 years of exposure (Hermanus, 2006). Further evidence of the high prevalence of NIHL in South African mines is found in compensation payment data. Table 2 presents these results for the year 2004/2005. It is clear from the discussion that NIHL in South African mines are very prevalent and large-scale research into the incidence and prevalence of NIHL is necessary. An audit of the Department of Minerals and Energy in the RSA reported 1820 cases of NIHL in 2007 (Sonjica & Nogxina, 2008). The Chamber of Mines reported a positive downward trend in the number of NIHL cases since 2007 (Chamber of Mines, 2012). It is possible that reported NIHL cases could have been inflated soon after 2001 as baseline hearing testing was only mandated after 2001 per Instruction 171 (COIDA, 2001).

Table 2-1 Compensation paid for NIHL in South African Mines

Year	Number of cases	Compensation paid
1998	5 395	R 68 113 616
1999	6 106	R 72 321 385
2000	4 965	R 65 004 865
2001	5 654	R 88 259 410
2002	14 457	R 102 308 555
2003	7 241	R 52 213 637
2004	3 849	R 77 067 521

Source: (RMA, 2005)

2.4. NIHL Mechanism of damage

Most hearing losses are associated with aging and excessive noise exposure without any other detectable ear disease (Dobie, 2001; Alberti, 2001). As hearing loss due to age is not preventable, prevention of NIHL (by noise level reduction, exposure reduction and the use of hearing protection) would in all probability do more to reduce the societal burden of hearing loss than medical and surgical treatment of all other ear diseases combined (Dobie, 2001). Elevated noise levels may lead to a number of non-auditory adverse effects, including elevated blood pressure and sleep interference (EPA, 1973; Nelson & Schwela, 2001) and may also interfere with communications and performance in the workplace, thus contributing to the occurrence of accidents (Girard, et al., 2009; Picard, Girard, Simard, Larocque, Leroux, & Turcotte, 2008). The most obvious consequence of exposure to intense sound is the occurrence of temporary and permanent hearing loss (Saunders, Dear, & Schneider, 1985). The most serious of these effects is irreversible hearing impairment. More subtle are the underlying physiological and anatomical consequences. The mechanism of NIHL and research findings in this area will be explored in the following section.

Perception of sound depends on the conduction of mechanical sound energy through the ossicles of the middle ear to the hydraulic medium of the cochlea. Middle ear injury from noise is rare and can occur only with extremely high sound pressure levels (Dobie, 2001). Research on human cadaver tympanic membranes (TM) demonstrated that extreme sound pressures, equivalent to at least 180 dB SPL, need to be present to perforate the TM (Garth, 1994). TM perforations with conductive and sensorineural hearing loss are part of the clinical picture of acoustic trauma[7] but not of NIHL (Dobie, 2001). The effects of sudden, explosive peaks of impulse noise may cause substantial mechanical disruption of middle and inner ear structures (May, 2000).

NIHL, due to exposure to continuous noise at hazardous intensities, causes a sensorineural hearing loss that is slow to develop (McReynolds, 2005). Once the mechanical energy (a result of the movement of the tympanic membrane caused by the sound waves) from the middle ear reaches the cochlea, it is translated into neural afferent information by the hair cells of the organ of Corti within the spiral structure of the cochlea (May, 2000). Figure 2 is a schematic representation of the ear and cochlea as illustrated by Kurmis and Apps (2007). Figure 3 shows a cross section of the basilar membrane and sensory cells (outer and inner hair cells) of the cochlea.

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[7] Gloric (1980) suggested that the term noise-induced hearing loss should describe the loss which is produced over a long period of time from exposure to long-term noise. A single incident, e.g., an explosion or a blow, that has caused the hearing loss, should be called acoustic trauma.

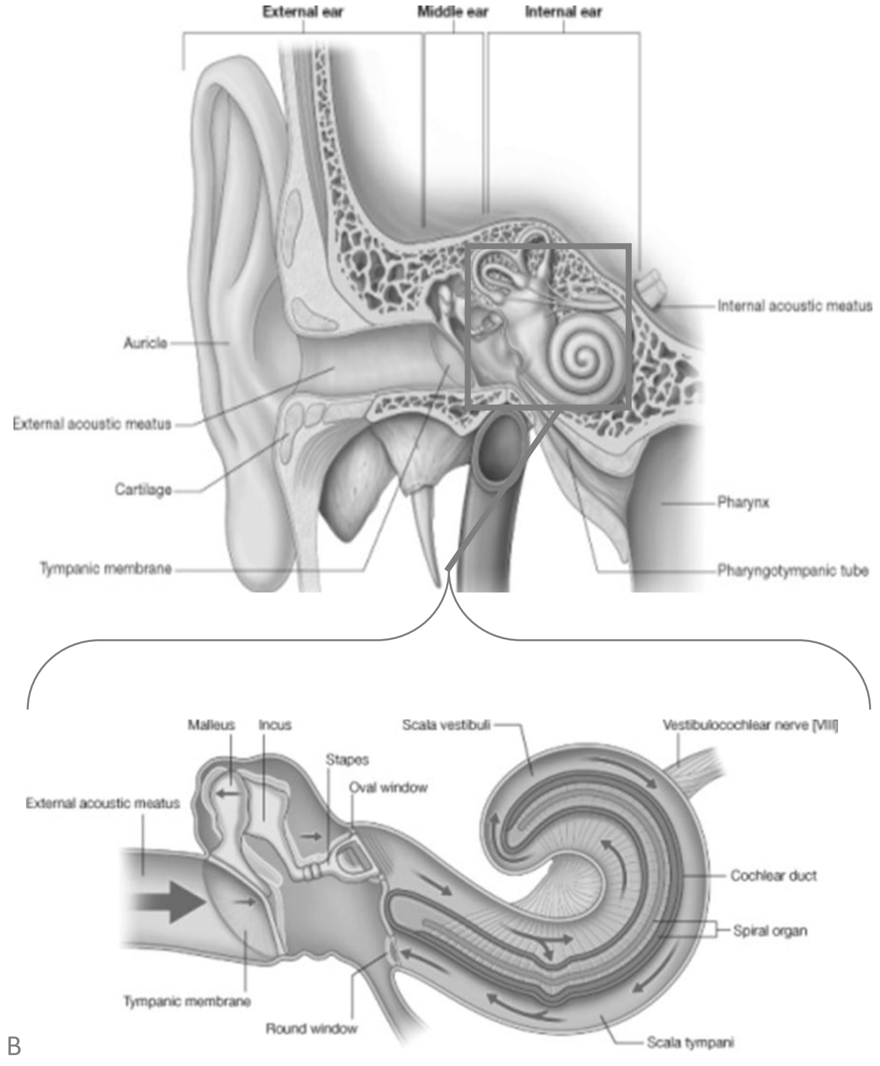

Figure 2-3 (A) The ear and cochlea (B) Regions of the cochlea showing the sound conduction path. Source: Kurmis & Apps (2007)

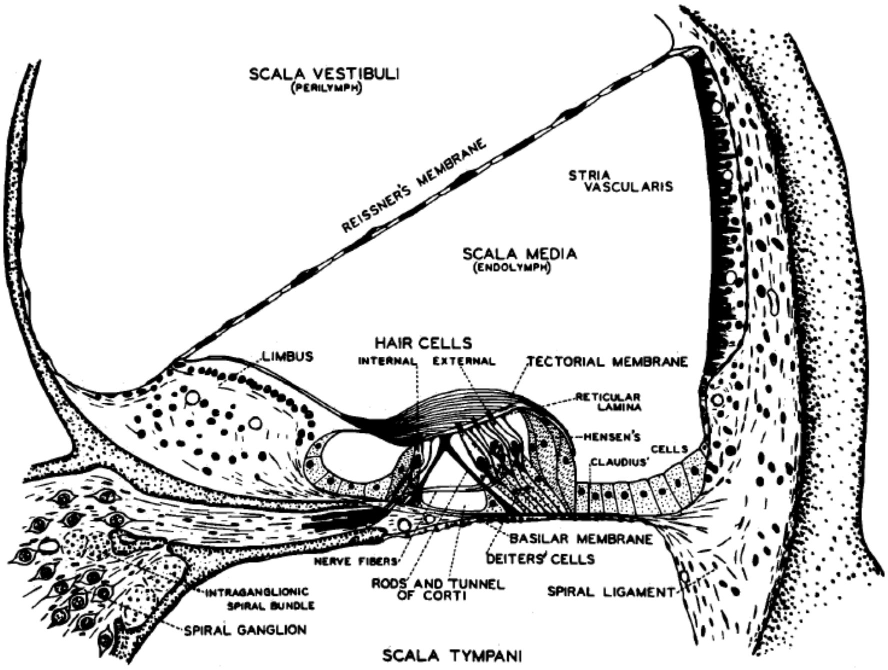

Figure 2-4 Cross section of the basilar membrane showing sensory hair cells of the cochlea. Saunders, Dear, & Schneider (1985)

Noise causes a broad set of physical changes in the major cellular systems in the cochlea. The most vulnerable structures in the cochlea are the outer hair cells (OHC) in the basal part of the cochlea. The basilar membrane is tonotopically organised with the lowest frequencies preferentially transduced at the apex and the highest frequencies at the base (Dobie, 2001). On the basilar membrane the OHCs in the area which responds to 4 kHz and the adjacent areas of 3 and 6 kHz are most susceptible to damage (Alberti, 2001; Kurmis & Apps, 2007). This is where the ear is most sensitive, in part because of the harmonic amplification of the ear canal and in part because of an unqualified sensitivity (Dobie, 2001; Alberti, 2001).

The inner hair cells (IHC) transfer signals via afferent neurons to the brain, whereas the vulnerable OHC act as a cochlear amplifier by enhancing the basilar membrane movements. Both types of hair cells possess a bundle of sensory hairs (stereocilia[8]) which react on sound stimulation by causing membrane depolarisation, neurotransmitter release and finally a generation of action potentials in the described attached cochlear nerves (Henderson, Bielefeld, Harris, & Hu, 2006). Changes to the stereocilia of the cochlear hair cells lead to diminished hearing sensitivity (based on hearing threshold testing) called a temporary threshold shift (TTS) and permanent

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[8] Delicate hair-like structures, arranged in staggered rows on the apical surface of the sensory cells i.e. the inner and outer hair cells of the cochlea's basilar membrane (Alberti, 2001)

threshold shift (PTS) (Le Prell, et al., 2007; Henderson, et al., 2006; Dobie, 2001; May, 2000). There is a window of time between the disconnections of the tips of the largest stereocilia from the tectorial membrane in which the tips can reattach. TTS may partially be the consequence of the stereocilia damage and repair (Henderson & Hamernik, 1995). After initial exposure to hazardous noise the stereocilia lose their stiffness and consequently their ability to vibrate in response to sound and a reversible hearing loss is caused (TTS) (Dobie, 2001). After repeated hazardous exposures the stereocilia of the OHCs become permanently damaged (OHCs die) and a PTS (hearing loss) results. Damage to the OHC is greater than that of the IHCs presumably because OHCs experience a direct shearing force at their stereocilia, whereas the IHC stereocilia are stimulated by viscous drag. OHCs also have most of their long axis exposed to mechanical stress while IHCs have supporting cells on all surfaces. OHCs are furthermore closer to the point of maximum basilar membrane travelling wave displacement than the IHCs (Henderson & Hamernik, 1995).

Different pathways of hair cell death have been described. These investigations used cochlea dissection and histochemical methods for surface examination of chinchilla cochleae (Bohne, Harding, & Lee, 2006; Bohne, Zahn, & Bozzay, 1985; Gao, King, Zheng, Ruan, & Liu, 1992; Harding & Bohne, 2007; Harding, Bohne, & Vos, 2005; Henderson & Hamernik, 1995; Henderson, et al., 2006; Le Prell, et al., 2007; Kopke et al., 2005; Majno & Joris; 1995) . Investigators Majno and Joris (1995) stated that the term “necrosis” should be reserved for dead cells, regardless of which death pathway the cells had followed. A study by Bohne and colleagues (Bohne, Harding, & Lee, 2006), investigating the pathways of death for cochlear OHCs, report three possible pathways. These are:

1. *Oncotic* – swollen, pale-staining cell with a swollen nucleus;
2. *Apoptotic* – shrunken, dark-staining cell with a pyknotic nucleus; and
3. a *newly defined* third pathway – no basolateral plasma membrane but cellular debris arranged in the shape of an intact OHC with a nucleus deficient in nucleoplasm.

Previous experiments (Bohne, Zahn, & Bozzay, 1985; Henderson & Hamernik, 1995) reported that hair cells die for as many as 30 days after the hazardous noise exposure. Since OHCs die over a relatively long period, knowledge of the mechanisms of cell death may lead not only to methods of prevention but also to rescue after a hazardous noise exposure (Henderson, et al., 2006).

Recently, research on the cellular bases of NIHL has led to new avenues for protection through the use of prophylactic drugs (Henderson, et al., 2006). These research efforts have cast new light on the mechanism of NIHL (TTS and PTS) (Gao, et al., 1992; Kopke et al., 2005; Henderson, et al., 2006; Rabinowitz, Pierce Wise, Hur Mobo, Antonucci, Powell, & Slade, 2002; Le Prell, Yamashita, Minami, Yamasoba, & Miller, 2007). The hearing function of the cochlea not only depends on the structural integrity of the hair cells and surrounding support cells but also on the local vascular structures, and the immediate microenvironment (May, 2000). The following table summarises research findings in respect of the mechanism of NIHL.

Table 2-2 Noise-induced hearing loss: Area of the cochlea where damage occurs, description of the mechanism of damage and illustrations

Cochlear area	Mechanism of NIHL
Structural integrity of the hair cells and surrounding support cells	• Noise can damage most of the cell populations in the cochlea, but the OHC are the most prominent pathological target (Henderson, et al., 2006). • Because of noise stereocilia can be broken, fused, or have broken tip links that lead to loss of structural integrity (Henderson, et al., 2006; Saunders, Dear, Schneider, 1985). • The ability of the stereocilia to act as mechanoelectrical transducers can also be reduced due to a loss of permeability of protein transduction channels in the cell membrane surrounding the stereocilia (Patuzzi, 2002). • The tips of the stereocilia on outer hair cells (OHC) can be removed from their points of insertion into the tectorial membrane, leading to a loss of sensitivity (Henderson, et al., 2006; Gao et al., 1992; Alberti, 2001). • Damage to pillar cells (supporting cell type) has also been observed after impulse noise and high-level continuous noise (115 dB SPL). The loss of the pillar cells interferes with the local impedance of vibration leading to a disruption of the mechanically coded vibration of the organ of Corti. In addition, the loss of the pillars may also contribute to the loss of OHC (Henderson & Hamernik, 1995; Henderson, et al., 2006). • High-level noise can lead to acute swelling of the stria vascularis, swelling that is associated with loss of intermediate cells of the stria. The swelling disappears over time, but the loss of intermediate cells is permanent. Therefore, the overall size of the stria vascularis shrinks as a long-term result of noise exposure (Henderson, et al., 2006). • Impulse noise exposures can damage the cochlea by causing direct mechanical damage. Depending on the intensity of the impulses, the organ of Corti can be ripped from the basilar membrane. Pillar and

Cochlear area	Mechanism of NIHL
	Hensen's cells can be destroyed, or their structural contributions in the organ of Corti can be compromised. In addition, cell junctions between HC, Deiters' cells, and Hensen's cells can be broken (Henderson & Hamernik, 1995;Henderson, et al., 2006). • With more severe noise exposures, the pathology spreads to include IHC death (Henderson, et al., 2006).

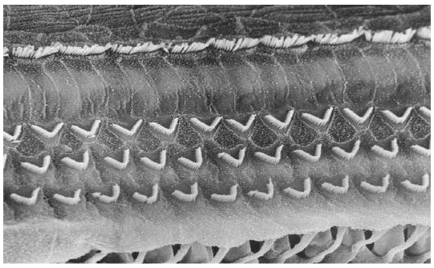

Figure 2-5 Scanning electron micrograph showing the normal organisation of the organ of Corti. View is of the apical membrane of the single row of IHCs (top) and 3 rows of OHC (bottom). Notice the orderly arrangement of stereocilia (Picture retrieved from http://www.d.umn.edu/~jfitzake/Lectures/DMED/InnerEar/IEPathology/StereociliaDamage.html)

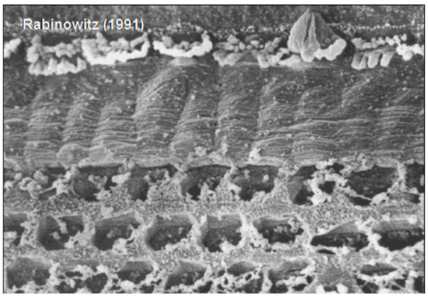

Figure 2-6 Disruption of IHC stereocilia and loss of OHC in the basal turn of the cochlea following noise exposure (90 dB A noise for 8 hours) 6 months earlier. This damage produced a profound hearing loss (Picture retrieved from http://www.d.umn.edu/~jfitzake/Lectures/DMED/InnerEar/IEPathology/StereociliaDamage.html)

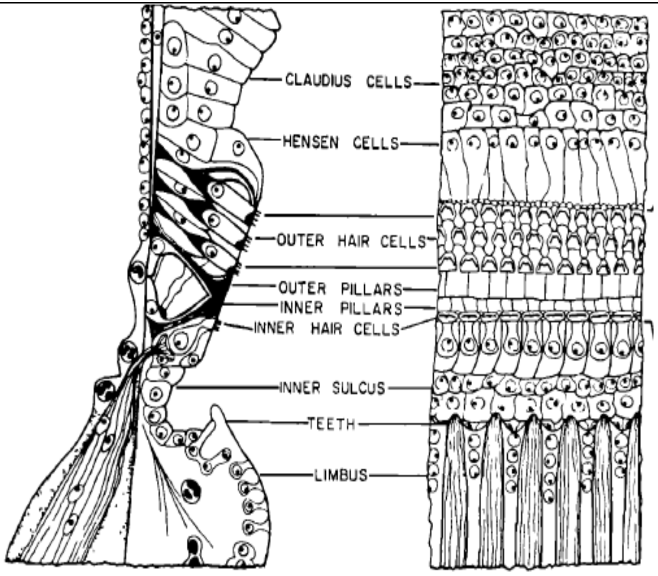

Figure 2-7 A line drawing of the hair cells of the organ of Corti with a cross section view. Source: Saunders, Dear & Schneider (1985)

Local vascular structures and immediate microenvironment of the organ of Corti	• Factors such as leakage of extracellular fluid into the microenvironment and damage to support cells, vascular and neural structures may be playing a role in hearing loss secondary to loud noise (May, 2000). • Partly associated with damage to the lateral wall blood vessels, high level noise exposure can reduce cochlear blood flow (CBF) (Henderson, et al., 2006). • Other than the changes to the OHC structures another significant factor in the mechanism of NIHL is intense metabolic activity, which increases mitochondrial free radical formation (Kopke et al., 2005; Le Prell, et al.,

Cochlear area	Mechanism of NIHL
	2007). • According to investigators Kopke and colleagues (2005) mitochondrial injury plays an important role in NIHL based on an assumed mechanism of cell death due to excessive reactive oxygen species (ROS) (and toxic free radicals) generation within the mitochondria. The balance between the production of ROS and the cellular anti-oxidants (AO) defence capacity determines the overall levels of ROS in living cells (Kopke et al., 2005; Henderson, et al., 2006; Rabinowitz, et al 2002). Evidence for a role of free radicals in NIHL and noise-induced sensory cell death is convincing, yet researchers are not clear whether the presence of ROS within noise-damaged cochlear tissue leads to cochlear damage or if the ROS are a product of damaged or dying cells (Henderson, et al., 2006; Kopke, et al., 2005; Le Prell, et al., 2007). The exact origins of the increased ROS observed in the cochlea are currently speculative (Henderson, et al., 2006). • During high-level noise exposure, the IHC are highly active, leading to the release of large amounts of glutamate into the synapses with the type I fibres of the VIIIth nerve. The levels of glutamate in the synapses can overstimulate the glutamate receptors on the postsynaptic cells resulting in excitotoxicity, characterised by swelling of the postsynaptic cell bodies and dendrites (Henderson, et al., 2006; Sataloff & Sataloff, 2006). Over time, the swollen or ruptured dendrite terminals appear to recover and begin to function normally, suggesting that this type of damage may also contribute to TTS (Henderson, et al., 2006). • With more severe noise exposures the pathology may include loss of auditory nerve fibres and damage to stria vascularis (Henderson, et al., 2006).

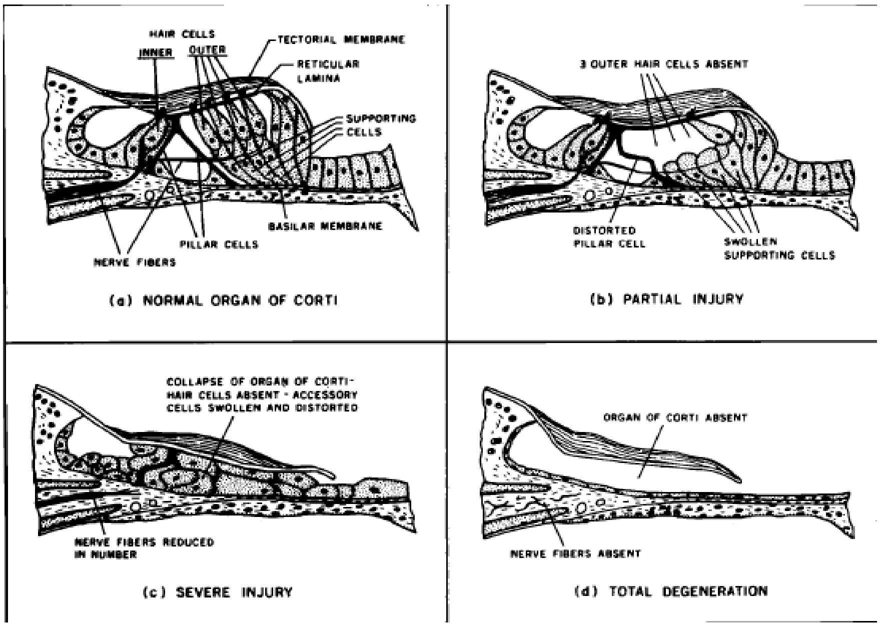

Figure 2-8 Different levels of damage to the organ of Corti. Source: Saunders, Dear & Schneider (1985)

Table 2.2 outlines areas of the cochlea that has shown damage or change in reaction to hazardous noise exposure. However, animal studies have repeatedly demonstrated that the relationship of these types of changes in the cochlea to decreases in hearing acuity is, at best, indirect (Henderson & Hamernik, 1995).

Factors such as leakage of extracellular fluid into the microenvironment, damage to support cells, vascular and neural structures as well as free radicals which may lead to cell death might be playing a role in hearing loss secondary to loud noise (as outlined in table 2.2). Based on the morphological appearance of combined focal lesions of different sizes, investigators Harding and Bohne (2007) conclude that many of the cochlear lesions due to excessive noise begin as pure OHC focal lesions, but with time, more OHCs in the area become injured and die, followed by pillar cells and IHCs.

It is noteworthy that the mechanism of damage to the cochlea differs depending on the nature of the damaging sound. Studies by Harding and Bohne (2007 & 2009) investigated the effect of a high-frequency pure tone (4 kHz) and a low-frequency pure tone (0,5 kHz) on the cochlea. For both pure tones, OHC focal lesions and combined focal lesions had substantially larger sizes than IHC focal lesions and the OHC lesions were almost twice as large in cochleae exposed to the 4 kHz pure tone compared to those exposed to the 0,5 kHz tone. On the other hand, IHC focal lesions had similar sizes, regardless of the exposure pure tone (Harding & Bohne, 2009). Two studies by Bohne and colleagues investigated whether the magnitude and pattern of cochlear damage is altered when exposure to noise is interrupted by regularly spaced rest periods (Bohne, Zahn, & Bozzay, 1985; Harding & Bohne, 2009). Rest has been shown to be protective for noise-induced hair-cell loss in general (Bohne, Zahn, & Bozzay, 1985). The results showed that rest periods during the exposure to damaging noise substantially reduced the development of focal lesions in the basal half of the organ of Corti from high-frequency noise (e.g., a 4-kHz pure tone). Also, rest reduced the formation of focal lesions in the apical half from a low-frequency noise (e.g., a 0,5 kHz pure tone). However, rest only partially protected the exposed chinchilla cochleae against the formation of focal lesions in the basal half of the organ of Corti for a damaging low frequency pure tone (Harding & Bohne, 2009). There was thus considerable less damage to the cochlea apex regions (low frequencies) when low-frequency sounds were made intermittent with the same total sound energy than in the basal area (Bohne, Zahn, & Bozzay, 1985). These observations lead the investigators to support the notion that the mechanisms for the development of focal lesions in particular, and hair-cell loss in general, differ in the basal and apical halves of the organ of Corti.

2.5. NIHL and the audiogram

NIHL causes a sensorineural hearing loss which is typically bilateral (American College of Occupational and Environmental Medicine (ACOEM), 2003). Asymmetric sources of noise, such as sirens or gunshots, can produce asymmetric loss (ACOEM, 2003). Because of the tonotopical organisation of the cochlea (with the lowest frequencies preferentially transduced at the apex and the highest frequencies at the base) one might expect an intense pure tone to damage the cochlear region that best transduces the tone to cause a hearing loss for the frequency of the stimulating tone. The maximum loss for pure tone exposure is estimated however to be approximately a half-octave above the offending frequency (e.g. 1 kHz tone will cause damage at 1,5 kHz) (Harding, et al., 2005; Dobie, 2001; Saunders, Cohen, & Szymko, 1991). This is where the greatest loss of hair cells occurs, near the upper edge of the exposure band (Harding & Bohne, 2007; Harding, et al., 2005). As explored in the previous section low-frequency sounds can also damage the high-frequency part of the cochlea (Dobie, 2001; Bohne, Zahn, & Bozzay, 1985; Bohne, Harding, & Lee, 2006). In chinchilla cochleae exposed to a 4 kHz pure tone, lesions were distributed throughout the basal half of the cochlea. In cochleae exposed to the 0,5 kHz tone, lesions occurred in the basal (high- frequency) and apical (low-frequency) area of the cochlea (Harding & Bohne, 2009). But considering the nature of noise exposure in the workplace, occupational noise is seldom centred around a specific pure tone. It is mostly broadband in nature and is defined by weighted measurements that are indicative of the response of the hearing mechanism (NIOSH, 1972). This weighted scale of noise measurement and noise hazard will be discussed in chapter three. In the following paragraphs the effect of occupational noise exposure on the audiogram will be discussed.

2.5.1. The notched audiogram

Broadband noise can cause widespread damage to the cochlea but the basal part of the cochlea shows the greatest changes, especially the 3 to 6 kHz area (Dobie, 2001). A notch in the audiogram greatest at 4 kHz has been known to be associated with excessive exposure to noise for more than a century (Clark, 2000; Harding & Bohne, 2009).In an 1860 textbook, Toynbee noted a decrease in hearing of the 5 octaves tuning fork, with a characteristic frequency of 4096 Hz, by patients who engaged in the hobby of sport shooting (Toynbee, 1860). This loss was also termed the "C5 dip" until the 1930s when audiometers and pure tone audiometry were available and the "4 kHz" classification was adopted (Clark, 2000). Despite the early recognition of the typical NIHL audiogram pattern, the progression of this loss was first studied systematically in cross sectional studies in a cross section of general workplaces in England and Wales (NIOSH, 1972; McBride, 2004). These results confirmed that with exposure to broad band, steady noise, or noise with an impulsive component, the first sign was a dip or notch in the audiogram greatest at 4 kHz with recovery at 6 and 8 kHz with an overall audiogram shape concave upward (Rabinowitz, et al 2006; NIOSH, 1972). Audiograms show a pattern which is usually bilateral and shows a typical “notch” in the 4 kHz range on the audiogram (Figure 8). As the loss proceeds, the notch becomes deeper and broader, extending toward both the 2 kHz and the 8 kHz range as it begins to seriously affect speech discrimination (May, 2000). This typical notch audiogram is shown in figure 8.

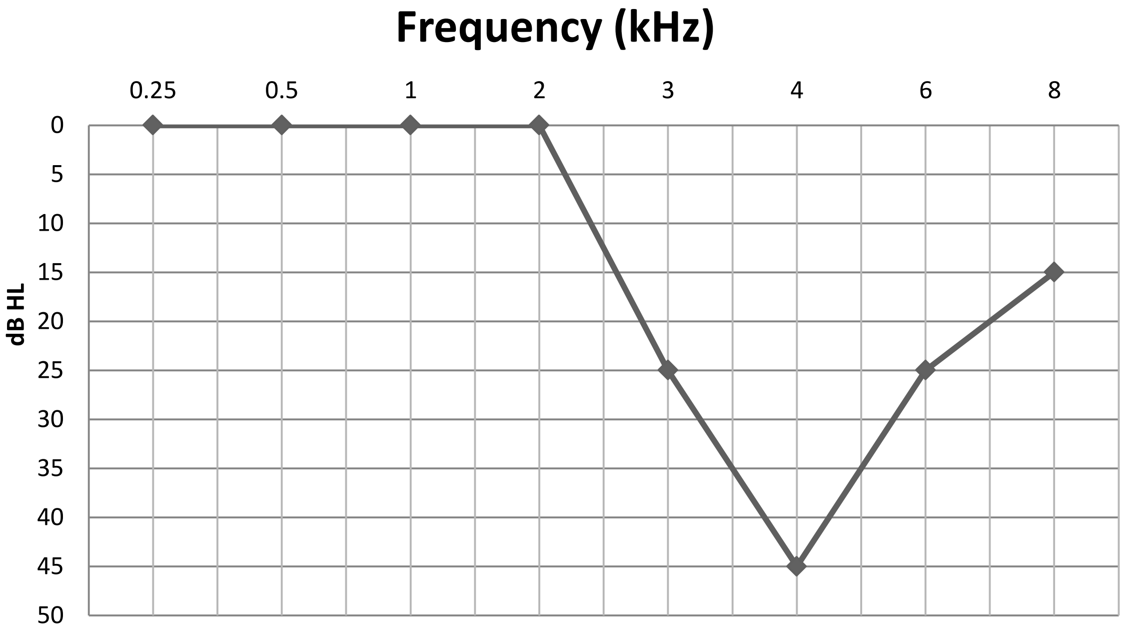

Figure 2-9: Audiogram demonstrating the typical notch of NIHL. Source: Rabinowitz et al. (2006)

Large studies involving thousands of workers with different exposure levels and durations were reviewed by ISO 1990:1999, ANSI (1996) and the U.S. Occupational Safety and Health Administration (US Department of Labor, 1983) based in part on the intergroup comparisons and analyses of Johnson (1978) (see chapter three for detailed consideration of these documents). All these groups published very similar tables of noise-induced permanent threshold shifts (NIPTS) based on the published data. Representative NIPTS values from the ISO 1990:1999 document are shown in figure 9.

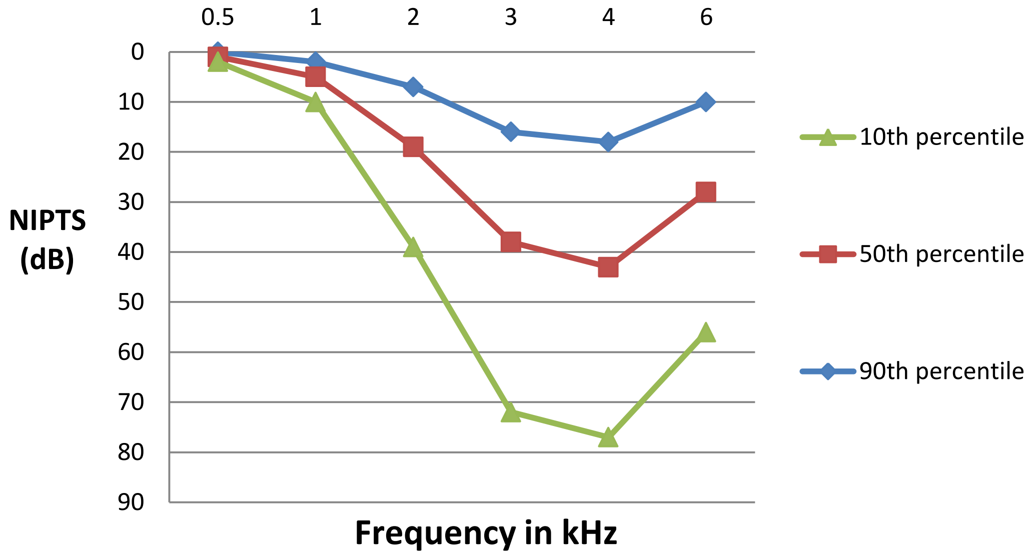

Figure 2-10: Median (50th percentile) and extreme (10th and 90th percentiles) NIPTS after 30 years of workplace exposure to 95 dB A. Source: ISO 1990:1999

The curves shown in figure 9 show plots of NIPTS values derived at by subtracting thresholds of control subjects from those of noise-exposed subjects[9]. A limitation of the ISO 1990:1999 and ANSI standards is that 8 kHz thresholds are not shown due to the lack of data from the underlying studies (ANSI, 1996; ISO 1990:1999). 8 kHz was shown to be an important frequency when clinical judgements are made about the typical notch observed in NIHL audiograms. Two recent, independent studies investigated the typical notch[10] observed in NIHL audiograms as a clinical tool to

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[9] Extensive field studies of NIHL, all performed before widespread regulation of occupational noise exposure, were combined with studies of age-related hearing loss by the International Organization for Standardization (ISO, 1990) into ISO 1999 (Dobie, 2008).

[10] A noise notch requires better hearing at both lower frequencies and at 8 kHz than at the notch frequencies (American College of Occupational and Environmental Medicine (ACOEM), 2003).

judge NIHL audiograms (Rabinowitz, et al 2006; McBride & Williams, 2001). Rabinowitz and colleagues compared clinical judgement of the notch to those of notch metrics. These objective notch metrics that relied on the amount of recovery at 8 kHz were used as an indicator of the depth of the notch. It was concluded that clinical judgments about the 4 kHz notch were consistent and compared well to objective notch metrics, but both investigators found that audiogram reviewers differed in their valuation of notch depth[11] (McBride & Williams, 2001; Rabinowitz, et al 2006). The objective criteria used by Rabinowitz and colleagues are those of Coles et al. (2000) and Niskar et al. (2001). When investigating the prevalence of a notched audiogram or in clinical judgements of NIHL the definition of the notch is critical (Wilson, 2011). Available metrics providing notch criteria are summarised in table 2.2.

Table 2-3 Notch criteria from Coles et al. (2000) and Niskar et al. (2001). Source: Rabinowitz et al. (2006)

	Application of the metrics	Notch criteria	Notes
Coles, Lutman, & Buffin (2000)	Published criteria for identification of an audiometric notch for use in medico-legal diagnosis of NIHL.	A high-frequency notch with the hearing threshold at 3, 4 and/or 6 kHz at least 10 dB greater than at 1 or 2 kHz and at least 10 dB greater than at 6 or 8 kHz	Because of distortion at 6 kHz, an adjustment would be necessary if certain earphone types were used.
Niskar, Kieszak, Holmes, Esteban, Rubin, & Brody (2001)	For use in identifying NIHL in the audiograms of adolescents tested in the National Health and Nutrition Evaluation Survey.	• Hearing-threshold level values at 0.5 and 1 kHz ≤15 dB; • Worst (i.e., greatest value) threshold at 3, 4 or 6 kHz at least 15 dB worse than the worst threshold value at either 0.5 or 1 kHz • A hearing threshold at 8 kHz at least 10 dB better than the worst threshold at 3, 4 or 6 kHz	

A number of researchers have studied the occurrence of the noise-induced notch at frequencies other than 4 kHz (McBride & Williams, 2001; Sataloff & Sataloff, 2006; Osei-Lah & Yeoh, 2010; Axelsson, 1979; Salmivalli, 1979). More than three decades

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[11] Notch depth is different to bulge depth (BD) as BD is used to define audiogram configuration. A simple BD statistic can be defined as the difference between the PTAs at 2, 3 and 4 kHz and at 1 and 6 kHz (Dobie, 2005).

ago researchers observed the notch at 6 kHz and concluded that the earliest change in hearing due to excessive noise exposure might be found at this frequency (Axelsson, 1979; Salmivalli, 1979). In a recent survey of the non-institutionalised population of the United States, the National Health and Nutrition Examination Survey (NHANES), data was collected from 2 819 women and 2 525 men between 1999 and 2004 (Ciletti & Flamme, 2008; Hoffman, Dobie, Ko, Themann, & Murphy 2010). Results from this survey revealed a small notch at 6 kHz for both men and women at younger ages (25 to 34 and 35 to 44 years). This notch was observed at the lower and upper percentiles. The observed 6 kHz notch in the NHANES data was attributed to an error in the reference value for audiometric zero when calibrating TDH-39 headphones on an NBS-9A (6 cm3) acoustic coupler (Hoffman, et al., 2010; Lawton, 2005). Another study by Lutman and Davis evaluated the hearing of young adults in the United Kingdom during a large random survey (Lutman & Davis, 1994). The researchers also raised concerns about the 6 kHz calibration bias after having found that the younger subjects (screened and unscreened) had unusually increased thresholds at this frequency. Rabinowitz and colleagues further warned that because of distortion at 6 kHz, an adjustment would be necessary if certain earphone types were used (Rabinowitz, et al., 2006).

Another explanation for the notch at 6 kHz provided by McBride and Williams (2001) was that the standardisation of hearing can explain the notch at 6 kHz. Hearing sensitivity is not the same across the range of audiometric frequencies represented in the audiogram. The hearing level (HL) reference levels are designed for testing hearing (Dobie, 2001). On the audiogram 0 dB HL is defined as the average threshold (across the frequency range) of hearing of normal hearing young adult subjects free of otologic disease (ANSI, 1996). The normalised shape of the audiogram should thus be a straight line, yet Robinson proposed that the reference standard at 6 kHz is set several dB too low with the result that a normal audiogram would have a notch at that frequency (Robinson, 1988).

The 4-6 kHz notch has also been attributed to other causes such as viral infections, skull trauma, hereditary hearing loss, ototoxicity, acoustic trauma, sudden hearing loss and multiple sclerosis (Martini, Stephens, & Read, 2007; Sataloff & Sataloff, 2006; Osei-Lah & Yeoh, 2010). In a recent study of 149 outpatients it was found that 62 (41,6%) had notched audiograms with only three of these participants reporting histories of noise exposure (Osei-Lah & Yeoh, 2010). These results show that 4 kHz notches appear in audiograms of individuals with no significant exposure to noise. On the contrary 4 kHz notches can be absent in audiograms of individuals with extensive exposure to noise as shown by a recent study by Wilson (2011). This large study investigated the notches found in the audiograms of 3 430 veterans (Wilson, 2011). A notched audiogram (4 kHz) was observed in 40,6% of the participants with unilateral notches almost twice as prevalent as bilateral 4 kHz notches. These authors conclude that 4 kHz notches appear to be a random occurance in that most notches are unilateral with an equal likelyhood of occurance in the left and right ear. In conclusion the 4 kHz or any other high frequency notch without evidence of excessive noise exposure should not be deemed diagnostic of NIHL (Osei-Lah & Yeoh, 2010; Wilson, 2011) and conversely hearing loss with evidence of exposure to hazardous noise should not be disregarded as NIHL because of the absence of a high frequency notch.

2.6. Individual susceptibility and confounding factors in NIHL

According to the ISO 1990:1999 database, an exposure of 100 dB A for an 8 hour workday for 30 years (without the use of hearing protection) gives a median NIHL at 4 kHz of 45dB but with a range of 60dB between the 10th and 90th percentiles. From this example it is apparent that a noise-exposed individual may have normal hearing or severe hearing loss with the same noise exposure level and exposure time. Humans demonstrate differences in susceptibility to noise damage even under carefully controlled exposure conditions (Henderson & Hamernik, 1995).

Several factors play a role in individual susceptibility (vulnerability) to NIHL. These factors range from accompanying environmental factors such as non-occupational noise exposure and vibration, and biological factors such as smoking, age, gender, genetics, ototoxic drugs and illnesses such as tuberculosis (Pyykkö, Toppila, Zou, & Kentala, 2007). Some of these agents may accompany hazardous noise in or away from the workplace. The resultant hearing loss is often greater than would be expected for either agent alone (Dobie, 2001). Yet it is important to note that these agents cannot lower the levels and durations of noise at which the hazard begins (Kryter, 1965; Dobie, 2001; Martini, Stephens, & Read, 2007).

Although there are many factors contributing to individual susceptibility to NIHL the factors most relevant to this study are discussed in the following sections. The interaction of age and NIHL will be highlighted, with reference to the effect of smoking and genetics on susceptibility to NIHL. Finally the effect of gender and ethnicity on NIHL will be considered.

2.6.1. Age

A contentious issue when estimating the effect of noise on hearing relates to the effect of aging on hearing loss. Because of the many similarities and interactions between NIHL and age-related hearing loss (ARHL) many authors believe that it is imperative to take into account the contribution of ARHL when determining the effect of noise on hearing (Ciletti & Flamme, 2008; Niskar, Kieszak, Holmes, Esteban, Rubin, & Brody, 2001; Pyykkö, et al., 2007; Dobie, 2001; Hoffman, et al., 2010; Flamme, Deiters, & Needham, 2011). In a study by Dobie (2008) predictions were made about the burden of NIHL and ARHL in the United States (US). This author estimated that 10,5% of all hearing loss cases in the US can be attributed to NIHL. Although Dobie (2008) uses a different methodology than the large WHO study (Nelson, et al., 2005a) and criticises some aspects of the methodology of a large WHO study their estimates of the contribution of NIHL is similar (WHO study, 9%). Dobie (2008) arrives at the conclusion that most, estimated to be as high as 80%, of the burden of adult-onset hearing impairment is age-related.

Several similarities between ARHL and NIHL make it difficult to distinguish the relative contribution of aging and noise to hearing loss (Dobie, 2008). Firstly ARHL and NIHL show similar pure tone patterns on the audiogram (sensorineural, bilateral, with high frequencies affected more than low frequencies). Secondly, as described in the previous section, the audiogram of a person affected by NIHL typically demonstrates a notch in the 3 to 6 kHz region but this notch may be obliterated by age-related threshold shifts, as the worst affected threshold in ARHL is often at 8 kHz. Finally other tests (audiometric, oto-acoustic emissions, imaging etc.) do not reliably distinguish ARHL from NIHL (Dobie, 2008). Studies have shown that the effect of noise on hearing is most in the early years of exposure to hazardous noise levels but in later years (older than 65) the age-related hearing loss contributes more to the total loss of hearing than NIHL (Dobie, 2008; Pyykkö, Toppila, Howard, Jacobs, & Kentala, 2007b). Researchers experimenting with mice confirmed these findings when they reported that animals showed less of a change in hearing when they had been exposed to hazardous noise and already had a large PTS, compared to animals with little or no previous NIHL (Perez, Freeman, & Sohmer, 2004). These authors suggest that hearing loss lowers the intensity of subsequent noise exposures and make the cochlea less sensitive. It is thus possible that initial NIHL affects subsequent NIHL as the noise levels are in effect lowered. ARHL could have the same "protective" effect as NIHL.

The mechanism of progressive pathological changes and damage to the cochlea caused by aging (and resulting in hearing loss) could be related to nutritional, vascular, toxic, genetic and other factors (Alberti, 2001; Bohne, Harding, & Lee, 2006; Clark, 2000; Dobie, 2008; Harding, et al., 2005; Martini, Stephens, & Read, 2007; Ferrite & Santana, 2005; Fransen et al., 2008). Very often these same factors have been indicated to increase a person's susceptibility to NIHL.

2.6.1.1. Age, smoking and NIHL

In a study done by Ferrite and Santana (2005), the joint effects of *smoking*, age and occupational noise exposure were investigated in a cross-sectional cohort of 535 male workers. For smoking and noise exposure the estimated sum of the hearing loss was higher than the effects from each isolated variable in the 20 to 40 year age group. Increased susceptibility demonstrated in this study was confirmed by numerous other studies (Agrawal, Platz, & Niparko, 2009; Pouryaghoub, Mehrdad, & Mohammadi, 2007; Wild, Brewster, & Banerjee, 2005). In the Ferrite and Santana report (2005) the higher estimated hearing loss associated with a combination of smoking and age among the group who had not been exposed to occupational noise was also evident. The synergistic effect of smoking, noise exposure, and age on hearing loss, found in this study, is consistent with the biological interaction. These authors suggest that the synergistic effect of smoking, noise exposure, and age on hearing loss can be explained by the underlying mechanisms of damage relating to vascular changes and consequent cochlear hypoxia. In South Africa's population of mine workers the habit of smoking is very evident as confirmed by a study investigating the prevalence of smoking in a group of platinum mine workers (n=25 274) (Cheyip, Nelson, Ross, & Murray, 2007). Although a decrease in cigarette consumption has been reported since legislation became more stringent (1990s) the prevalence of smoking has been reported to be about 43% of all platinum miners.

2.6.1.2. Age, genes and NIHL

Recently observed pathophysiological changes to the cochlea, due to gene mutations, have led to more research in genetic hearing loss (Martini, Stephens, & Read, 2007). There is increasing evidence that genetic mutations could determine an individual and intrinsic predisposition to noise damage (Le Prell, et al., 2007; Harding, et al., 2005; Martini, Stephens, & Read, 2007; Konings, et al., 2009; Bovo, Ciorba, & Martini, 2007). Many of the contributions to the study of genetic factors in NIHL derive from laboratory research on genetically modified animals. Bovo and colleagues (2007) refer to three gene loci contributing to NIHL susceptibility that have been identified in strains of mice, 10 that contribute to ARHL, and six loci that promote both (Bovo, Ciorba, & Martini, 2007). The investigators concur that any gene that weakens the ear functionally or structurally would make it more susceptible to noise damage. Harding, Bohne and Vos (2005) further investigated the relationship between NIHL and an age-related gene found in mice. Their results confirmed that mice with the age-related gene (*Ahl)* were more susceptible to NIHL than those without.

2.6.1.3. Age correction and the NIHL audiogram

Because of the interaction and co-existence of ARHL and NIHL age correction by use of available databases could be used to establish the contribution of NIHL to the total hearing loss (Dobie, 2001). It is argued that the individual’s total hearing loss should almost always be treated as the sum of at least two components, NIPTS and age-related permanent threshold shift (ARPTS). If HTL refers to the hearing threshold level for a given frequency or pure-tone average: HTL= NIPTS+ARPTS (Dobie, 1992). Extensive field studies of NIHL, all performed before widespread regulation of occupational noise exposure, were combined with studies of ARHL by the International Organization for Standardization (ISO, 1990) into ISO 1990:1999, a standard that describes the separate and combined effects of aging and noise on hearing thresholds in populations of varying age, sex, and noise exposure history (ISO, 1990). Data used in the ISO 1990:1999 was derived from a technical report prepared by Johnson (1978). These distributions were derived from the first National Health Examination Survey (NHES I, 1959–1962). It has subsequently been suggested that the National Health and Nutrition Examination Survey 1999–2004 distributions could be used as a possible replacement for Annex B (unscreened database) in ISO 1990:1999 (Hoffman, Dobie, Ko, Themann, & Murphy, 2010). The ISO 1990:1999 is widely used to estimate the contribution of age and noise to the individual or group's hearing threshold levels (Ciletti & Flamme, 2008; Hoffman, et al., 2010; Dobie, 2005; Dobie, 2008; Dobie, 2007; Flamme, et al., 2011; Pyykkö, et al., 2007).

Even though this data-base is viewed as the best available summary of the permanent effects of noise exposure on hearing thresholds investigators are warned about important pitfalls when using population standards for comparison (Dobie, 2008). Pitfalls include non-random selection of study groups as this could introduce biases that will make comparison to a standard invalid (Dobie, 2006). When using the ISO 1990:1999 the choice of which annex to use for comparison is very important. This International Standard allows for two possibilities presented by two different databases: Annex A represents an "otologically normal population ("highly screened")" (ISO, 1990, p. 1). It further assumes median thresholds of 0 dB HL at age 18 years. This assumption has been countered by population data from the United States NHANES (1999-2004) that showed thresholds between 0 and 7 dB HL for this age group (Flamme, et al., 2011). Annex B includes results from subjects "for an unscreened population (ISO, 1990, p. 1). This database includes some people with unreported occupational noise exposure, but is more representative of the general population (Dobie, 2008). For an unscreened group Annex B would be the most suitable comparison group. When making comparisons to the ISO standard or any other population standard it is important to note which thresholds are used for comparison. For Annex A thresholds of either ear could be used, where "better ear" thresholds are used in Annex B (ISO 1990:1999). It is not specified however, how these thresholds were derived at. It is possible that the better ear was derived at by using pure tone average (PTA) (Dobie, 2006) or it is likely that the ear contributing to the better ear distribution could vary with frequency, depending on which ear have the better thresholds at that frequency (Flamme, et al., 2011). The latter assumption has been proven by analysis of the raw data tapes (Hoffman, Dobie, Ko, Themann, & Murphy, 2010).

Finally, when making comparisons it is important to choose the appropriate methods of statistical analysis. Because Annex A and B show positively skewed distributions (where means (averages) are greater than medians (the mid-point) and to a larger extent spread above the median than below it), median values and other percentiles were used to describe the data. Similar descriptors should be used when comparing data to the ISO databases (Dobie, 2006).

2.6.2. Gender

A recent study by Flamme, Deiters and Needham (2011) investigated cumulative pure tone threshold distributions from the National Health and Nutrition Examination Survey (NHANES) III and the 1999–2004 data (which can be generalised in respect of a population without significant history of exposure to occupational noise) by gender, ethnicity, age, ear, and the stimulus frequency. They found that pure tone hearing thresholds were worse for men than for women, and although the differences became more pronounced with increasing age and at higher frequencies, the differences were present across the age span and in each race/ethnicity category (Flamme, et al., 2011).

Adolescent and young adult males have been shown to have worse hearing thresholds than females (Le Prell, Hensley, Campbell, Hall III, & Guire, 2011) and these gender-based differences extend into adulthood, as the results of a study by Ciletti and Flamme (2008) with a large cohort of males (N=3275) and females (N=3711) demonstrate. These researchers used data from NHANES 1999-2004 and a large cohort of rural subjects (Keokuk County Rural Health Study (KCRHS)). Results indicated that rates of hearing impairment among men were twice as high as among women.

Even in the absence of occupational noise exposure men show significantly poorer threshold results than women. These results may be explained to some extent by women being less exposed to leisure noise (Pyykkö, et al., 2007). The study done by Le Prell and colleagues (Le Prell, Hensley, Campbell, Hall III, & Guire, 2011), notwithstanding the limited sample size (N=56), showed a statistically reliable relationship between personal music player use and lower thresholds in female subjects. They provide greater noise/sound exposures in males than in females as a possible explanation for greater hearing loss in males than in females, but the results might also indicate greater susceptibility to NIHL in males than in females.

As the other large studies based on the NHANES data (Flamme, et al., 2011; Ciletti & Flamme, 2008) have not controlled for non-occupational noise exposure as a variable, it is also possible that the argument for susceptibility for hearing loss may be reversed. Non-occupational noise exposure might not play a significant role and women might be less susceptible to hearing loss in general. The latter statement is confirmed by different correction factors in international and other standards for females and males that indicate better hearing thresholds (overall) in females across different age groups (ANSI, 1996; ISO 1990:1999). Several studies confirm better hearing in general in females (Henselman, Henderson, Shadoan, Subramaniam, Saunders, & Ohlin, 1995; Flamme, et al., 2011; Ciletti & Flamme, 2008; Dreisbach, et al., 2007, Agrawal, et al., 2010; Nelson, et al., 2005a). In a study on the effects of gender on hearing thresholds a significant gender effect was also found at the ultrahigh frequencies (14000-16000 kHz) with better thresholds for female subjects (Dreisbach, et al.,, 2007).

Many other authors have found a significant and relatively large difference in vulnerability or susceptibility for NIHL between men and women (Berger, Royster, & Thomas, 1978; ISO, 1990; Smith, Davis, Ferguson, & Lutman, 2000; Rabinowitz, et al 2002). In a comprehensive study by the WHO a comparative risk assessment was done incorporating the results from 16 studies and 14 WHO epidemiological subregions (Nelson, et al., 2005a). Results from this study demonstrated that the effects of the exposure to occupational noise are larger for males than females in all subregions and higher in the developing regions. NIHL reportedly affects males at a 3:1 higher rate than females (Nelson, et al., 2005a) indicating greater susceptibility to NIHL.

2.6.3. Race

The hearing threshold levels of occupational noise-exposed individuals have also been compared between subjects of different ethnicities (Rabinowitz, et al 2002; Ishii & Talbott, 1998). In an extensive study investigating hearing thresholds of a large group of US army soldiers (N=39006) a significant difference was found between black and white soldiers' hearing thresholds after correcting for age and noise exposure (Henselman, et al., 1995). Black soldiers had better hearing than white soldiers across the frequency range. The study of Rabinowitz and colleagues (2002) showed similar results, despite small numbers of racial sub groups: black subjects showed a trend toward better audiometric thresholds and oto-acoustic emissions (OAE).

In a study by Ishii and colleagues (1998) black metal fabricating workers had a PTA (1, 2, 3, 4 kHz) of 17,71 dB compared to their white counterparts who showed a PTA average of 25,99 dB, a statistically meaningful difference ($p < 0.01$). Several reports on the effect of eye colour in susceptibility to NIHL (Carter, 1980; Ishii & Talbott, 1998; Carlin & McCroskey, 1980; Cunningham & Norris, 1982) indicate that individuals with blue eyes are more susceptible to noise-induced cochlear damage than are green or brown-eyed individuals which may be related to race since eye colour is highly dependant on race. This clinical research suggests that melanin,[12] especially in the stria vasclaris of the cochlea, appears to act as a protective agent (Ishii & Talbott, 1998). In accordance with these results researchers Pyykkö, Toppila, Zou, and Kentala (2007) found that skin sensitivity to sunburn (pigmentation) seems to affect vulnerability to NIHL. This has also been attributed to higher levels of melanocytes and their protective capability against noise damage in the inner ear. These results and conclusion might explain why black subjects have presented with significantly better hearing thresholds compared to white subjects and less susceptibility to NIHL than the latter.

In South Africa a very large porportion of the mining workforce is black (referred to as African) compared to a much smaller white group. Anglogold Ashanti, the

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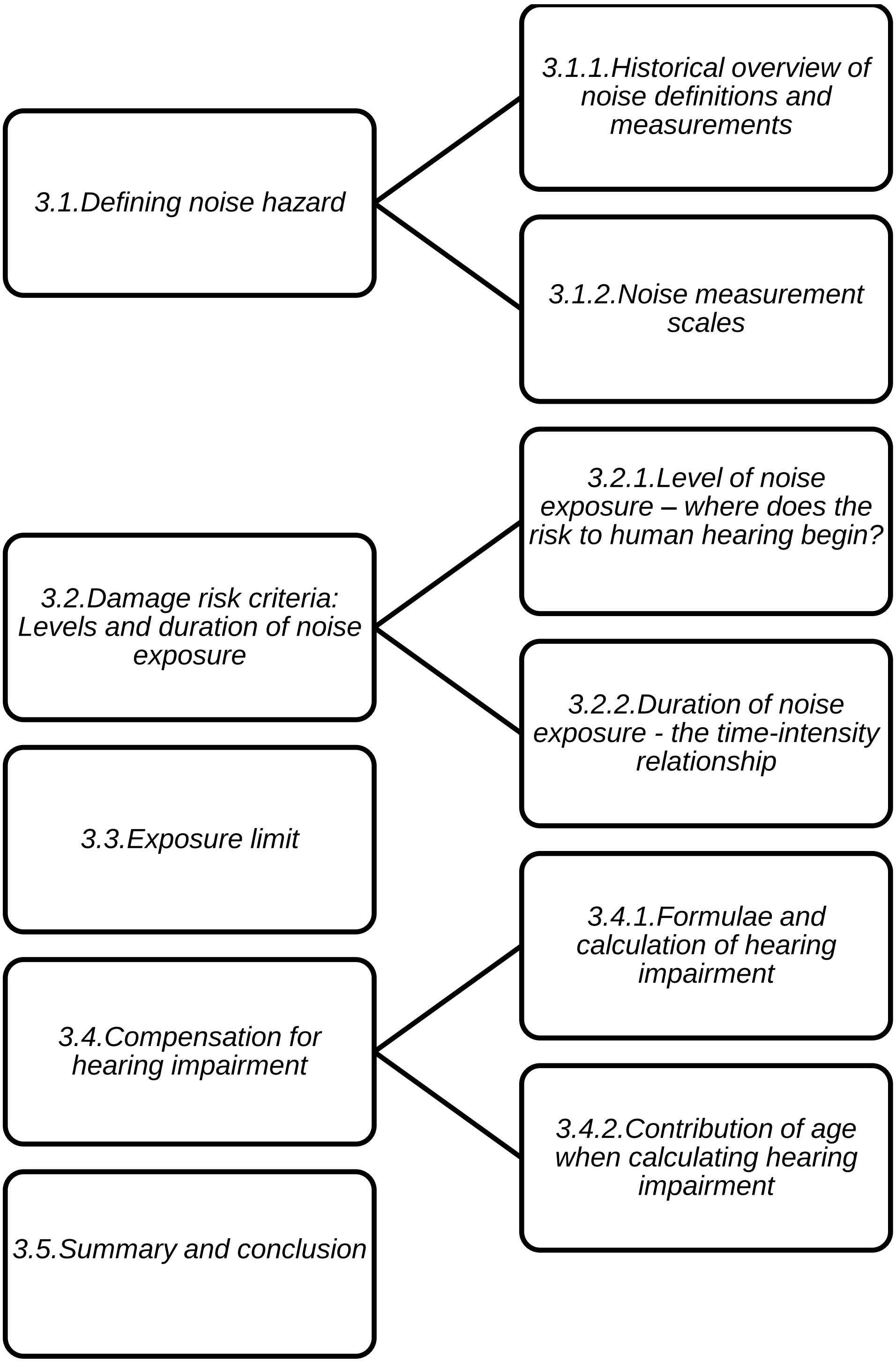
[12] Melanin is the the dark amorphous pigment that covers the posterior surface of the eye which appears in skin and exists in differing amounts in eyes and skin. Blue eyes are at one end of the continuum and are almost entirely lacking in melanin, whereas dark brown eyes are at the other extreme and have a relatively greater amount of melanin (as with darker skin colour) (Carlin & McCroskey, 1980).

goldmine whose workers were investigated in this study, for example permanently employed 19 897 black mine workers compared to 3 820 white workers in 2010 (excluding infrastructure support workers) according to their employment equity report (AngloGoldAshanti, 2010). To date only one large scale study has been done investigating NIHL in South African mine workers. This study investigated NIHL in a cohort of white South African male mine workers (N=2667) (Hessel & Sluis-Cremer, 1987). As no black or female workers were included in this cohort, comparisons between these groups and respective susceptibility to NIHL are unavailable.

2.7. Summary

In this chapter, a historical overview was provided for NIHL. The discussion has shown that NIHL was described very early on in history and is still very prevalent today. In South Africa, as elsewhere on the globe, NIHL is also prevalent and has been identified as a major occupational hazard in mining in South Africa. The mechanism of NIHL and the nature of the structural and other changes in the cochlea have been discussed and new research endeavours have been highlighted. The literature overview has provided insight into the effect of NIHL on the audiogram and controversies in the field, specifically related to the “noise notch”, have been considered. Finally different confounders that might affect outcomes of hearing threshold results of this study were discussed. It is clear from literature that age plays a very important role in hearing and NIHL cannot be investigated without taking the effect of aging into account. Other important risk factors, such as smoking, ethnicity (race) and gender influence susceptibility to NIHL and affect hearing thresholds. Available published reports suggest that black subjects tend to have better hearing thresholds overall as do female subjects.

3. Damage risk and impairment criteria



Scheme of the literature review followed in Chapter 2 and 3:

Noise-induced hearing loss (NIHL): Overview

Chapter 2

- Historical overview of NIHL;
- Prevalence of NIHL world wide;
- Prevalence of NIHL in RSA mines;
- NIHL: Mechanism;
- NIHL effect on the audiogram;
- Confounding factors and individual susceptibility.

Damage risk and impairment criteria

Chapter 3

- Damage risk criteria: Defining noise hazard
- Historical overview of noise definitions and measurements
- Noise measurement scales
- Damage risk criteria: Levels and duration of noise exposure
- Level of noise exposure where risk to human hearing begins
- Duration of noise exposure- Time-intensity trading relation
- Exposure limit
- Compensation of hearing impairment
- Formulae and calculation of hearing impairment
- Contribution of age when calculating hearing impairment

3.1. Defining noise hazard

Attempts at limiting human exposure to noise have been based on damage risk criteria (NIOSH[13], 1972). Prevention of a disease such as NIHL requires that the contributory hazard be carefully defined and descriptions of how it should be measured be provided. Proposing damage risk criteria for any biological hazard is a very difficult and complex problem (Glorig, 1980). Several disciplines are involved when defining risk criteria for noise. Assumptions must be made regarding the anatomical and physiological nature of the damage to the cochlea; the physical characteristics of the noise, measurements of noise and hearing, and administrative matters specific to the country must be taken into consideration. The purpose of such criteria would be to define maximum permissible levels of noise stated

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[13] National Institute of Occupational Safety and Health (NIOSH) is not a regulatory agency, but one of its roles is to make recommendations to the Occupational Safety and Health Administration (OSHA) of the regarding areas—such as occupational noise exposure—that OSHA regulates for workplaces in the USA (Dobie, 2008).

durations, which if not exceeded, would result in an acceptably small effect on hearing levels over a working lifetime of exposure (Botsford, 1967; Fletcher & Munsen, 1933; Dear, 1987; US Department of Labor, 1983; NIOSH, 1998; NOHSC, 2000; NIOSH, 1972; SANS10083:2004, 2004).

3.1.1. Historical overview of noise definitions and measurements

After initial reports of noise-related hearing loss had emerged the contributory relationship between noise and hearing became evident (Glorig, 1980). However, prior to 1950, reliable data on the amount of noise that posed a hazard to hearing were not available. Before World War II, due to lack of uniformity in instrumentation and hearing and noise units and scales, studies from around the globe often yielded varying results (Johnson, Papadopoulos, Watka, & Takala, 2006). Initially the hazard of a noise source was defined as the integrated effect of the components of the noise on the ear (Free, 1930). Without consensus about the harmful elements of a specific noise source establishing criteria for damage risk was hampered. Early measurements of noise were very rudimentary and often subjective. One example of an early measurement included the use of a tuning fork and a watch (Galt, 1930). The tuning fork was struck and the time required for the tone to decay to a level equal to that of the noise, as judged by the ear, was plotted and used to define the “deafening produced by the noise” (Galt, 1930). By 1950 researchers were in agreement that noise measurements needed to yield information about the frequencies present in the noise, the amplitudes of each and the effects of these frequencies on the ear (Free, 1930; Galt, 1930, Fletcher & Munsen, 1933; Fletcher, 1938, Rosenblith, 1953 cited in NIOSH, 1972).

At presented it is accepted that the effects of sound on a person depend on three physical characteristics of the sound: amplitude, frequency, and duration (NIOSH, 1998). Early reports of sound measurements describe obtaining an audiogram of a range of ordinary noises (Galt, 1929). The first report of a portable sound level metre was given in 1933 (Osbon & Oplinger, 1933). Yet, even after measurements of sound were possible the hazard of noise to hearing remained difficult to measure (Free, 1930; Galt, 1929; Marvin, 1932; Fletcher & Munsen, 1933; Fletcher, 1938). Similar to the “tuning fork” measurement (Galt, 1929) other measurements made by early noise metres were fraught by a lack of consensus on the definitions of underlying concepts and on which scales to use. Abbot (a research physicist at the University of Michigan, 1934) gave an unadorned account of the problem: “The principal difficulty is that larger numbers often do not represent louder sounds. The decibel seems mysterious at best, considering that 50 dB at 1000 cycles is louder than 60 dB at 100 cycles because the ear is more sensitive to the higher frequency, and 50 dB at 100 cycles is louder than 60 dB at 1000 cycles because the loudness of low-pitched sounds increases more rapidly than higher pitched ones... The fundamental difficulty seems to be that there are at least eight scales in general use for expressing the magnitude of a sound and that five of them are decibels scales” (Abbot, 1935). It was only after 1950 that noise measurements were adapted to take into account that the human ear is more sensitive to some sounds than others (NIOSH, 1972).

3.1.2. Noise measurement scales

Early noise measurements were based on overall sound pressure level (Kryter, 1950). Since then those noise measurements have been replaced by measurements that are more indicative of the response of the hearing mechanism (NIOSH, 1972). Data on minimum audible field sensitivity indicated that the ear is most sensitive to acoustic stimuli in the frequency range of 2000 to 4 kHz, and less sensitive to frequencies both below and above this range (Sivian & White, 1933, Fletcher & Munsen, 1933, Harding & Bohne, 2009). This knowledge led to the implementation of a weighted scale for the measurement of noise hazard. The first standard for sound level metres was published by the American Standards Association in 1936 (American Standards Association, 1936). This standard shows two frequency weighting curves, “A” and “B”, which were modelled on the ear’s response to different levels of sound. The most common weighting today is “A-weighting”, dB A, which is similar to Curve A of the 1936 standard (NIOSH, 1972). The A-weighting network[14] gives essentially full weight to frequencies between 700 and 9000Hz (within 3 dB) and considerably less weight to frequencies outside of this range (Dobie, 2001). Use of A-weighting has been accepted as a rating of noise in a

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[14] Decibels measured using the A-weighting network of the sound level metre are referred to as dB A.

reasonably similar manner as would the human ear (NIOSH, 1972). Since the publishing of the first guidelines document for noise measurement in the United States of America (USA) the use of the A-weighted sound level for the measurement of noise hazard has become the most widely used (NIOSH, 1972). Results from several studies have confirmed the efficacy of using A-weighted sound levels in rating hazardous exposures to noise (Botsford, 1967; Passchier-Vermeer, 1968 in Passchier-Vermeer & Passchier, 2000, NIOSH, 1972). As a result, the A-weighted scale has been incorporated in many occupational noise standards internationally, including South Africa (DME, 2003; EU, 2003; NIOSH, 1998), and is commonly used in measuring noise to evaluate its effect on humans (NIOSH, 1998). Another weighting system that is sometimes used for the measurement of impulse sounds is the C-weighting system. Use of C-weighting defines the frequency response of the instrument and eliminates very low frequency impulses and sounds that are harmless (Johnson, et al., 2006).

In an effort to assess the excess risk of hearing impairment, as a function of levels and durations of occupational noise exposure, many field studies were conducted between 1950 and 1970 on hearing loss in noisy workplaces in Europe and the United States (Dobie, 2007). After that period such studies became difficult to control as a result of hearing conservation programmes that were widely implemented in most industrialised countries (Dobie, 2007). As the use of hearing protection in most industrialised countries since the early 1980s would confound determination of dose-response relationships for occupational NIHL, current risk assessment is based on a re-analysis of data from previous surveys (NIOSH, 1998). International risk criteria will be discussed in the following section.

3.2. Damage risk criteria: Levels and duration of noise exposure

Figure 3.1 demonstrates the aspects taken into account when defining damage risk criteria for occupational exposure to noise:

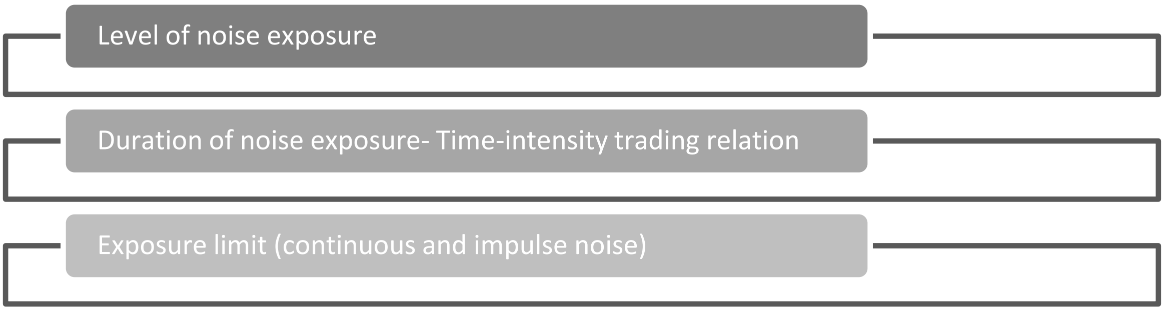

Figure 3-1 Aspects considered in damage risk criteria for occupational noise exposure

In the following sections aspects included in figure 3.1 will be discussed in relation to defining the damage risk along with international and other standards where damage risk criteria are considered.

3.2.1. Level of noise exposure – where does the risk to human hearing begin?

The damage to hearing caused by occupational noise was evident early on as described in section 3.1. Defining the level of the noise where risk to human hearing begins depended on results from noise and hearing surveys before the 1980s when widespread hearing conservation programmes were implemented (Dobie, 2008). Not many large scale studies were done and many of the standards defining damage risk used data from the same studies. Defining the level of noise where damage risk begins and the development of the most widely accepted noise exposure standards are tantamount. In the following paragraphs the most widely accepted noise exposure standards (ISO 1990:1999; ANSI S3.44; NIOSH (1972/1998); EPA (1973)) and subsequent studies or surveys that led to assumptions about the level where damage to hearing begins will be discussed.

In the 1960s, the *International Organization for Standardization* (ISO[15]) began an effort to summarise the available NIHL data into a comprehensive document (standard number ISO 1990:1999) estimating risk of hearing loss from specified levels and durations of noise exposure. Data for the ISO 1990 (1971) document were derived from a study conducted by Baughn (1971) on a population of automobile factory workers (N=6735) (Baughn, 1971). The data from this study were a source of controversy and reservations with regard to its reliability (Dear, 1987; Prince, Stayner, Smith, & Gilbert, 1998; Dobie, 2007). It was criticised for instance for inaccurate noise measurements, incorrect calibration of equipment and non-exclusion of temporary threshold shift due to recent noise exposure (Dear, 1987; Dobie, 2007). The ISO 1999 was subsequently revised and is now known as the ISO 1990:1999[16] (ISO, 1990). The current edition of ISO 1990:1999 (ISO, 1990) is based on Johnson's (1978) synthesis of data from Great Britain and Passchier-Vermeer's (1974) summary of several European and American field studies.

ISO 1990:1999 remains in force as published in 1990 and has been republished with very minor changes by the American National Standard Institute (ANSI) as ANSI S3.44 (ANSI, 1996; Dobie, 2007). Dobie (2007) in his reassessment of the data sets used in the NIOSH (1998) study, the ISO 1990:1999 and EPA (1973) data concludes that the ISO 1990:1999 model remains the best available summary of the permanent effects of noise exposure on hearing thresholds (Dobie, 2007). Estimates from the ISO 1990:1999 (ISO, 1990) yield excess risk values of less than 1% for 80 dB A[17], 3% for 85 dB A, and 8-11% for 90 dB A (for the average of 0,5 kHz, 1 kHz, and 2 kHz).

Other risk criteria documents, widely used, differ in their findings. One such document was that of NIOSH (NIOSH, 1972) (see footnote 13) and was based on a

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[15] ISO (International Organization for Standardization) is the world's largest developer and publisher of International Standards. ISO is a network of the national standards institutes of 163 countries, one member per country, with a Central Secretariat in Geneva, Switzerland, that coordinates the system (ISO, http://www.iso.org/iso/about.htm, 2010).

[16] The ISO 1990:1999 is currently under revision (ISO, http://www.iso.org/iso/about.htm, 2010). The previous review process for ISO 1990:1999 took at least 10 years to complete.

[17] The A-weighting network gives essentially full weight to frequencies between 700 and 9000Hz (within 3 dB) and considerably less weight to frequencies outside of this range (Dobie, 2001). Use of A-weighting has been accepted as a rating of noise in a reasonably similar manner as would the human ear (NIOSH, 1972).

large scale study conducted to assess the excess risk of material hearing impairment as a function of levels and durations (e.g., 40-year working lifetime) of occupational noise exposure. The data used for the NIOSH risk assessment was collected by Lempert and Henderson in 13 noise and hearing surveys (collectively known as The Occupational Noise and Hearing Survey (ONHS)) between 1968 to 1971(NIOSH, 1998). It was concluded that for a 40-year lifetime exposure in the workplace to average daily noise levels of 80, 85, or 90 dB A, the excess risk of material hearing impairment was estimated to be 3%, 16%, or 29%, respectively (PTA 0,5 kHz, 1 kHz and 2 kHz). On the basis of this risk assessment, NIOSH recommended an 8-hour time-weighted average (TWA[18]) exposure limit of 85 dB A. Some of the aspects of these analyses were controversial, however. Both ISO 1990:1999 and NIOSH (1998) predict increased risk as the exposure level rises. However, ISO 1990:1999 predicts a higher risk for frequency combinations that include higher frequencies, with more NIHL expected. The NIOSH (1972) definition of hearing impairment did not include high frequencies even though the 4 kHz audiometric frequency was recognised as being sensitive to noise (Dobie, 2007). Subsequently Prince and colleagues (Prince, et al.,1998) re-evaluated the NIOSH data using different hearing impairment definitions as this will influence the magnitude of excess risk estimates. The re-evaluated data were used to compile the NIOSH 1998 revised criteria document (NIOSH, 1998). Including these modifications (for a hearing impairment definition of 25 dB average hearing threshold level at 1000, 2000, 3000 and 4 kHz) the excess risk was estimated as 8% for workers exposed to an average daily dose of 85 dB A over a 40-year working lifetime, 1% at 80 dB A and 25% at 90 dB A (Prince, et al.,1998). Prince and colleagues concluded that a serious limitation of these studies were the limited amount of data for risks below 85 dB A. Extrapolation was used to estimate risks below 85 dB A, but quantification of the risk is uncertain (Prince, et al.,1998).

Results from a study by Stephenson et al. (Stephenson, Nixon, & Johnson, 1980) found no temporary threshold shifts occurring for broad band noise exposures less than 80 dB A after 24 hour noise exposures. These data are in line with the

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[18] TWA= Time-Weighted Average= the A-weighted level that, if continuously present for eight hours, would pose a risk to hearing equivalent to the varying exposure measured by the dosimetre (Dobie, 2001).

Occupational Safety and Health Administration (OSHA)[19] recommendation that TWA exposures be less than 80 to 81 dB A for durations longer than 16 hours (NIOSH, 1998). Very narrow-band sounds such as pure tones are more hazardous than broad-spectrum sounds of the same A-weighted sound level (Dobie, 2001). The ISO 1990:1999 and the ANSI S3.44 suggest that 5 dB might be added for such sounds to obtain estimates of equivalent hazard.

In 1973 the Environmental Protection Agency published a document in which a 75 dB A exposure limit was recommended (EPA, 1973). An 8-hour level of 75 dB A was recommended as the level to protect *"public health and welfare with an adequate margin of safety".* As previously mentioned this criteria document included the data by Baughn (1973), which had probably been contaminated by temporary threshold shifts, and therefore may not be entirely valid to estimate permanent noise effects. All the other models described confirm an excess risk of material hearing impairment at 85 dB A for an 8-hour exposure time.

Risk estimates from some of these documents are summarised in table 1.1 (NIOSH, 1998). These estimates are based on a 40-year working lifetime exposure for an 8-hour working day to occupational noise and show the percentage risk estimates for the different criteria documents as discussed.

Table 3-1 Comparison of models for estimating the excess risk of material hearing impairment at age 60 after a 40-year working lifetime exposure to occupational noise (8-hour TWA), by definition of material hearing impairment

	0,5-1-2-kHz Definition (% hearing impairment)					1-2-3 kHz Definition (% hearing impairment)			1-2-3-4-kHz Definition (%hearing impairment)	
Average exposure level dB A	1971-ISO	1972-NIOSH	1973-EPA	1990-ISO	1997-NIOSH	1972-NIOSH	1990-ISO	1997-NIOSH	1990-ISO	1997-NIOSH
90	21	21	22	3	23	29	14	32	17	25
85	10	10	12	1	10	16	4	14	6	8
80	0	2	5	0	4	3	0	5	1	1

(Source: NIOSH, Criteria for a Recommended Standard, Occupational Noise Exposure. Revised Criteria, 1998)

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[19] OSHA is the main USA federal agency charged with the enforcement of safety and health legislation (US Department of Labor, 1983).

From table 3-1 it is clear that the excess risk estimates derived from the 1971-ISO, 1972-NIOSH, 1973-EPA, and 1997-NIOSH models are reasonably similar except for the estimates derived from the ISO 1990 model that are considerably lower than those derived from the other models. These inconsistencies may be due to differences in the statistical methodology or in the underlying data, as discussed. Nonetheless, these models confirm an excess risk of material impairment at 85 dB A.

As limited survey studies on noise exposure and hearing are available before the implementation of widespread hearing conservation programmes and these criteria documents incorporated data from available studies, noise standards around the globe have been influenced by these documents. As an example, in the United States, the formal Washington Industrial Safety and Health Act (WISHA) sets the maximum permissible exposure limit for an eight-hour working day at 85 dB A (Kurmis & Apps, 2007). This sentiment is largely reflected by the legislature of the majority of North American states and most other first world countries including Australia and South Africa. In South Africa, for example, according to the regulations for noise-induced hearing loss of the Occupational Health and Safety Act (1993), a “noise-rating limit”, referring to the value of the 8-hour rating level, is set at 85 dB A and above (OHSA, No. R. 307., 2003). This is also the recommendation of the South African Bureau of Standards (SABS[20]) through the South African National Standards, SANS 10083:2007 (SANS10083:2007, 2007). A 2003 directive of the European Parliament and the Council of the European Union, stipulates an amendment to regulatory conditions within member states that took effect in 2006, to further reduce the “lower [acceptable] exposure action values” to 80 dB A (EU, 2003).

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[20] The South African Bureau of Standards (SABS) is a statutory body that was established in terms of the Standards Act, 1945 (Act No. 24 of 1945) and continues to operate in terms of the latest edition of the Standards Act, 2008 (Act No. 29 of 2008) as the national institution for the promotion and maintenance of standardisation and quality in connection with commodities and the rendering of services (www.sabs.co.za).

3.2.2. Duration of noise exposure - the time-intensity relationship

As described in section 3.2.1 most of the damage risk criteria assume risk to human hearing, for eight-hour daily exposures, begins at about 85 dB A. For shorter daily exposures, higher sound levels can be tolerated without appreciable risk (Dobie, 2001), but the appropriate trading relationship between time and intensity is not universally agreed upon. A trading relationship exists between exposure time and noise level, the product of the two being a measure of the total acoustical energy received (Ishii & Talbott, 1998). A functional definition of exchange rate (time-intensity trading relation) is the increase or decrease in the permissible noise level criteria as the time of permissible employee exposure at that level is halved or doubled, respectively (Sataloff & Sataloff, 1987). For example, an exchange rate of 5 dB A causes the permissible exposure time to be reduced from eight to four hours when the exposure level increases from 85 to 90 dB A. The most commonly used exchange rates incorporate either 3 dB or 5 dB per doubling or halving exposure duration (NIOSH, 1998). The principle behind the 3 dB exchange rate is that equal amounts of sound energy will produce equal amounts of hearing impairment (equal risk) regardless of how the sound energy is distributed in time (NIOSH, 1998; Kryter, 2009; Dobie, 2001). The following mathematical equation in figure 3.2 demonstrates how the doubling of sound energy yields an increase of 3 dB (NIOSH, 1998).

X= The exchange rate whereby energy is doubled

$$10\ \mathrm{Log}_{10}(A/B) + X = 10\ \mathrm{Log}_{10}(2\,A/B)$$

$$X = 10\ \mathrm{Log}_{10}(2A/B) - 10\ \mathrm{Log}_{10}(A/B)$$

$$= 10\ \mathrm{Log}_{10}(2)$$

$$= 10(0.301)$$

$$= 3.01\ \mathrm{dB}$$

Figure 3-2 Mathematical relationship demonstrating the equal energy rule

This equation would not yield a doubling or halving in intensity per 5 dB increment. The equal energy or 3 dB A rule was first proposed in 1955 by Eldred et al. (Eldred, Gannon, & von Gierke, 1955) and adopted by the ISO 1990:1999, NIOSH (NIOSH, 1998), the EPA guidelines (EPA, 1973), and the RSA standards document SANS 10083:2007 (SANS10083:2007, 2007). Not all standards support the 3 dB A rule however, OSHA (see footnote 6, page 9, chapter 3) for example abides by the 5 dB A rule instead of the 3 dB A suggested by the equal energy hypothesis (US Department of Labor, 1983). A reason proposed for the 5 dB exchange rate relates to the assumption that shorter noise exposures tend to be intermittent throughout the day and interrupted exposures cause less hearing loss than continuous exposure of equal duration (Dobie, 2001).

NIOSH (1972) initially supported the 5 dB A exchange rate but changed its opinion in the 1998 standard after research had indicated the credibility of the 3 dB A exchange rate. NIOSH (1998) incorporated data from field studies by Passchier-Vermeer (Passchier-Vermeer, 1974). The prediction models for hearing loss as a function of continuous-noise exposure level portrayed by this data corresponded well to the 3 dB A rule (equal-energy hypothesis) and also fit the data on hearing loss from varying or intermittent noise exposures.

Other authors, however, have been strong opponents of the 3 dB A rule (Dear, 2006; Sulkowski, 1980). These authors reveal shortcomings in the data of Passchier-Vermeer (1974), leading to questions about reliability and adequacy. These shortcomings include: insufficient noise measurements, inadequate histories of exposure duration, otological examinations and histories performed by inexperienced persons, audiometry conducted in rooms with high background noise, incorrect calibration of instruments, non-exclusion of TTS due to recent noise exposure, non-typical continuous or steady state noise exposure and questionable statistical techniques and interpretation of results (Dear, 2006; Sulkowski, 1980). Sulkowski’s final conclusion states that there is “no general agreement about trading relation between level and exposure time, but it seems that the 5 dB doubling rate is more appropriate than 3 dB time/ intensity trade-off value” (Sulkowski, 1980, p. 206).

While not all researchers have supported the 3 dB A rule an overwhelming general consensus favoured its use at a special meeting in 1982 at Southampton, England (Johnson, et al., 2006). Many leading investigators of noise-induced hearing loss reviewed the available literature with respect to the use of equal energy (Johnson, et al., 2006). The consensus reached at this meeting formed the basis of the ISO 1990 (1990). Later revised and named ISO 1990:1999, this revised document lent additional support to the equal-energy hypothesis. This group endorsed the use of equal energy as the most practical and reasonable method of measuring both intermittent and impact/impulse noise between 80 dB A and 140 dB A.

3.3. Exposure limit

Based on the equal energy principle that ISO 1990:1999 prescribes a unified measurement method for all types of noise, also impulsive noise, is recommended (ISO, 1990). Most noise standards are based on the notion that the risk of NIHL from all types of existing noise in industrial environments can be predicted on an energy basis as long as the peak levels do not exceed 140 dB C (SANS10083:2007, 2007; ISO, 1990; NIOSH, 1998). ISO 1990:1999 allows adding a 5 dB penalty to the measured noise if a noise is “impulsive”, based on the presumption that impulsive sounds might pose a higher risk of hearing loss. The penalty is based on the results by Passchier-Vermeer (1968), showing that the hearing levels of workers exposed to widely fluctuating noises developed significantly larger losses (approximately 5 dB higher at 4 kHz) than workers exposed to continuous levels.

This approach is not yet universally accepted, however, since accurate measurement of impulse noise exposure is obscured by the multidimensional portrayal of the noise, number of impulses, temporal spacing, etc. (Dobie, 2001; (Johnson, et al., 2006). The available longitudinal studies in industrial environments of impulsive character suggest that the penalty may not be necessary for all impulsive sounds (De Toro, Ordoñez, Reuter, & Hammershøi, 2011). A recent research study investigated the TTS resulting in a Distortion Product Otoacoustic Emmission (DPOAE) shift in 16 normal hearing subjects after exposure to impulse noise of different intensities (De Toro, Ordoñez, Reuter, & Hammershøi, 2011). The results from this study suggest that the risk of NIHL from impulsive exposures with peak levels below 117 dB C may be reasonably predicted according to the equal energy principle, but that the 5 dB penalty may be more suitable for noises with peak levels above 120 dB C. Although this study was done on a small sample, results indicated that the degree of hearing loss of workers exposed to low-level impulses

(113–120 dB C) could be predicted according to the standard; whereas the group exposed to higher peak levels (115–143 dB C) showed a significantly higher hearing loss.

In many industrial operations, impulsive noise occurs with a background of continuous noise. In answer to the question whether the effect of the combined exposure is additive or synergistic, NIOSH criteria (1998) concludes that " (i)f the effects are additive, the 85 dB A limit with the 3 dB exchange rate should be sufficiently protective, if the effects are synergistic, the same should still be protective to a smaller extent". NIOSH therefore recommends that the 85 dB A as an 8-Hour TWA be applicable to all noise exposures, whether from continuous-type noise, impulsive noise or a combination of both.

The WHO document and recommendations for a noise standard (Johnson, et al., 2006) summarise some features of legislation in various countries (1997). Table 3-2 below is the summarised results for a few countries with the RSA standard SANS 10083: 2007 (2007) added for reference.

Table 3-2 Some features of legislation in various countries (1997). Source: Johnson, et al., 2006

Country (Jurisdiction)	8-hour average A-weighted sound pressure level (dB)	Exchange rate (dB)	8h-average A weighted limit for engineering or administrative controls (dB)	8h-average A-weighted limit for monitoring hearing (dB)	Upper limit for peak sound pressure level (dB)
Australia (varies by state)	85	3	85	85	140 un-weighted peak
Canada (Federal)	87	3	87	84	140 C peak
(ON, PQ, NB)	90	5	90	85 (b)	
(Alta, NS, NF)	85	5	85		
(BC)	90	3	90		
United Kingdom	85	3	90	85	140 C peak
USA (e)	90 (TWA)	5	90	85	140 C peak or 115 A Slow
USA (Army and Air Force)	85	3		85	140 C peak
RSA: SANS 10083: 2007 (2007)	85 for 8-hour normalised exposure level limit	3	85	On hiring, and at regular intervals thereafter	140 C peak

3.4. Compensation for hearing impairment

Since the development of noise criteria documents and because NIHL has been recognised as a preventable occupational morbidity occupational NIHL has become compensable under laws in developed and developing countries including South Africa (Nelson, et al., 2005a). Compensation for occupational injury was documented as early as 2050BC on the Nippur tablet No. 3191 from ancient Sumeria. This tablet outlines a law providing monetary compensation for specific injury to workers' body parts. Ancient Greek, Roman, Arab, and Chinese law provided sets of compensation lists, with precise payments for the loss of a body part (Guyton, 1999). According to these schedules the value of an ear was based on its surface area. The first workers' compensation payment for occupational hearing loss in the United States of America was made in 1948 (Sataloff & Sataloff, 2006).

In South Africa compensation for occupational hearing loss was first introduced in 1941 as the Workmen's Compensation Act 1941 (No 30 of 1941) (COIDA, 1994). This law was subsequently replaced by The Compensation for Occupational Injuries and Diseases Act, 130 (COIDA) that was signed into South African law effective from 1 March 1994, to provide compulsory compensation for all employees under contract of employment (with a few exceptions) for death or personal injury suffered in the course of their employment. In 2001 a circular instruction in respect of the determination of permanent disablement resulting from hearing loss caused by exposure to excessive noise and trauma, known as Instruction 171, was published as part of COIDA (COIDA, Compensation for Occupational Injuries and Diseases Act, No. 130 of 1993. Circular Instruction No. 171, 2001).

Compensation for occupational NIHL paid by the RSA compensation fund is summarised in figure 3-3.

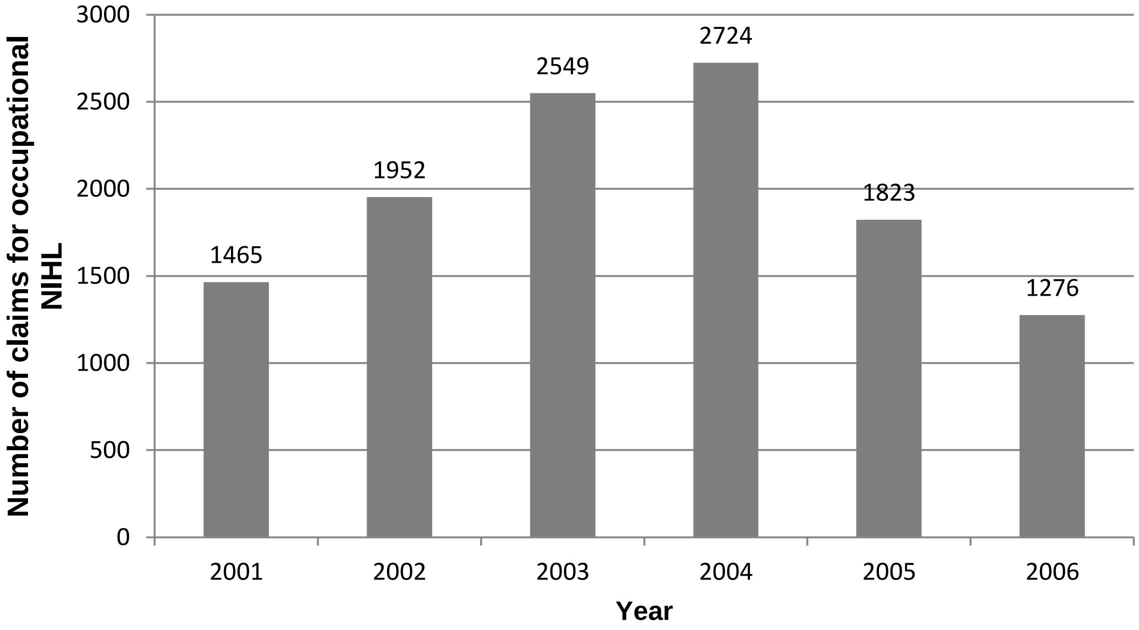


Figure 3-3 Claims submitted to the Compensation Fund during 2001-2006 (Source: RSA Compensation Fund, 2006).

Figure 3-3 shows that between 1276 and 2724 claims were submitted annually for compensation due to permanent hearing loss caused by industry noise in South Africa. NIHL was the occupational disease during this period for which the most claims were submitted, followed by post-traumatic stress disorder (with a maximum of 1624 claims in 2004) and then tuberculosis (with a maximum of 500 claims in 2002). The rise in claims to the compensation fund between 2002 and 2004 might be explained by baseline testing that became obligatory in 2001 (COIDA, 2001). It might thus be a reflection of the backlog in hearing loss claims (Barnes, 2008). It has been stated however that the number of compensable cases will rise again in future when the threshold for compensable hearing loss is breached (Hermanus, 2007).

3.4.1. Formulae and calculation of hearing impairment

In order to determine whether a person should be compensated for occupational NIHL and the amount of financial allowance under compensation laws determination and quantification of hearing loss on an accurate percentage scale is necessary. This is, however, a variable and difficult practice. The measurement of hearing involves a complex analysis of the hearing level for a variety of pure tones and speech (Dobie, 2001). The results of these measurements must then be related to an individual’s ability to communicate effectively in a variety of listening situations (Stander & Sataloff, 2006). Widespread variation exists in formulas for calculating hearing loss handicaps to arrive at disability (Dobie, 2008; Stander & Sataloff, 2006).

Authors Stander and Sataloff (2006) summarise the differences in the United States of America between the different states’ compensation agencies with regard to formulas used to calculate hearing impairment caused by NIHL (summarised in Table 3-3).

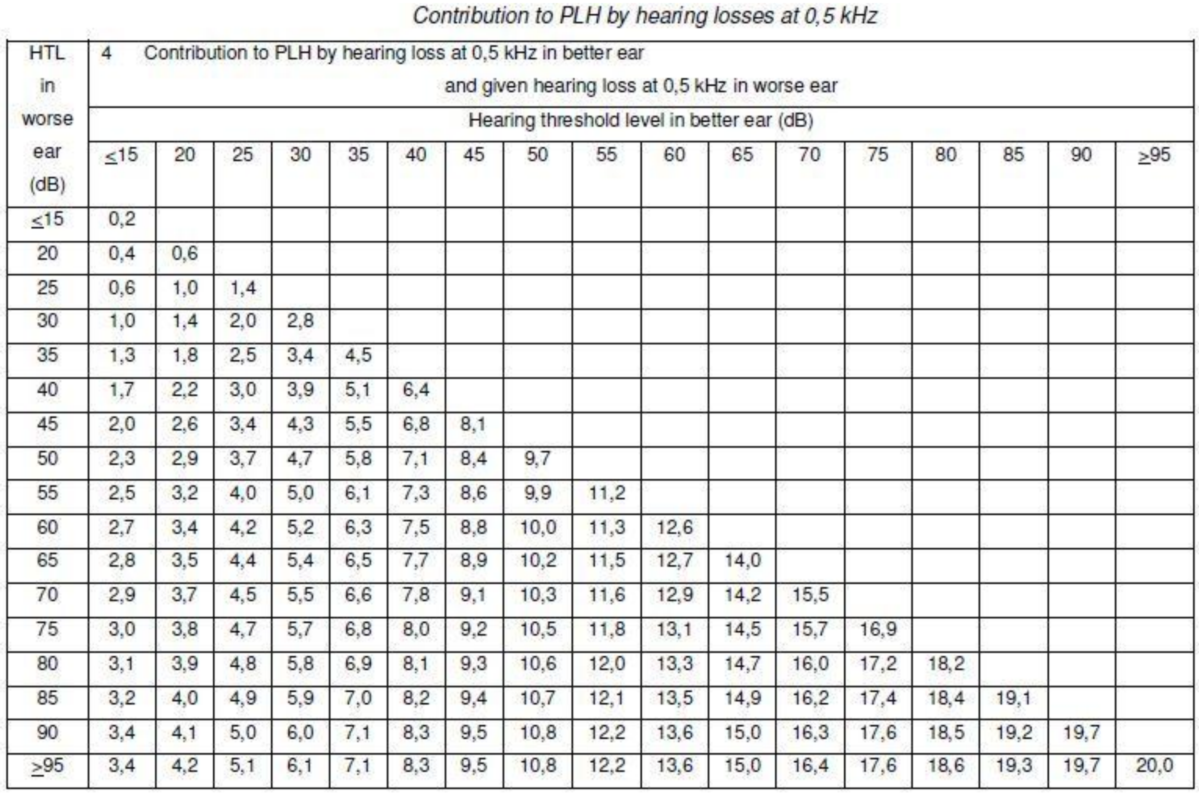
Table 3-3 Summary of US states federal compensation agencies with regard to the formulas used to calculate hearing impairment caused by NIHL (Source: Stander & Sataloff, 2006)

Summary of state formulae used	Summary of formulae's salient points
1. Two states use the 1949 American Medical Association (AMA) formula.	A weighted chart which used four frequencies: 512, 1024, 2048, and 4096 Hz. The 512- and 4096-Hz frequencies were valued at 15% each, the 1024-Hz frequency at 30%, and the 2048-Hz frequency at 40%. The ratio of hearing loss of the poorer ear to the better hearing ear was one to five.
2. Eighteen states use the 1959 formula adopted by the American Association of Ophthalmology and Otolaryngology (AAOO)(currently (2012) the AAO).	Three frequencies, weighted equally. 500, 1000, and 2 kHz, with a low fence of 25 dB. Hearing loss less than the low fence was considered satisfactory.
3. Two states use the 1979 version of the AAOO formula (currently the AAO (2012) formula).	Under the AAO current formula (2012), the percentage of hearing loss is calculated by taking the average, in decibels, of the hearing threshold levels in each ear for the frequencies of 500, 1000, 2000, and 3000 cps, or Hz. With a low fence of 25 dB and a high fence of 92 dB.
4. One state uses the CHABA recommendation, differing as to audiometric frequencies used, and the low-fence provision.	An average of 1000, 2000, and 3 kHz with low fence of 35 dB, and a better ear correction based on four to one.
5. Twenty-seven states, by far the majority, depend entirely on medical evidence, without specifying any particular formula or set of criteria.	

From table 3-3 it is clear that the formulae mostly used are those of the AAO 1979 formula (then the AAOO). The AMA changed its formula in 1979 to the AAO formula (Dobie, 2001). The first AMA endorsed approach (in 1947) to hearing impairment calculation was based on pure tone thresholds at 0,5 kHz, 1, 2 and 4 kHz with unequal weighting, 40% for 2 kHz, 30% for 1 kHz and 15% each for 0,5 and 4 kHz (Stander & Sataloff, 2006). This calculation was changed because it was too complex and also because otologists felt that the percentage hearing impairment overestimated the true handicap (Dobie, 2001). In 1959 the AAOO (currently the AAO (2012)) recommended a new rule that was then adopted by the AMA (1961).

Monaural impairment for each ear was based on PTA 512, beginning at 25 dB HL growing linearly at 1,5% per dB up to a maximum of 100% at about 92 dB HL. Better ear to worse ear weighting was 5:1 (Dobie, 2001). Because of the lack of consideration to any high frequencies in this calculation the American Academy of Otolaryngology (AAO) - Head and Neck Surgery (then the AAOO) - was concerned that the formula did not reflect a realistic degree of speech understanding in noise and recommended in 1979 adding 3 kHz to the calculation. The AMA accepted this recommendation in that year and still recommends this formula (Dobie, 2001). As can be seen from table 3-3 this calculation is the most widely used in the United States of America and is seen as an “acceptable compromise between accuracy and simplicity” (Dobie, 2001, p. 108).

In South Africa the percentage hearing impairment is referred to as percentage loss of hearing (PLH) and is calculated using the weighted calculation tables supplied by Instruction 171 (COIDA, 2001). After a thorough review of published literature and reports it was concluded that no published data is available on the evidence supporting the development of the PLH calculation tables. Internal reports from the South African goldmines suggest that it might be based on the Australian method of determining PLH (Edwards, 2010). The PLH calculations used in Australia was developed by Macrae (1988) for the National Acoustical Laboratories (NAL). These tables were designed to give more weight to frequencies that produced the highest degree of hearing handicap when impaired. This method is very similar to the South African PLH method, but for the inclusion of 1.5 kHz. Weighting is based on the estimated contribution of the different audiometric frequencies to the hearing handicap. Based on estimations awarding the maximum potential contribution to the handicap to 1 kHz and the lowest contribution to 3 and 4 kHz, PLH weighting is calculated (Greville, 2010; Macrae, 1988). Another aspect of these tables to take into consideration is that hearing of 0 dB across the frequencies also has a PLH value, even though there is no hearing loss. Figure 3-4 from COIDA’s Instruction 171 shows the calculation table for 0.5 kHz. Decibel HL values from the better ear (based on pure tone average (PTA)) and the worse ear interlink to give a value that is added to the values derived from similar tables for 1, 2, 3 and 4 kHz, the sum of which calculates the PLH.

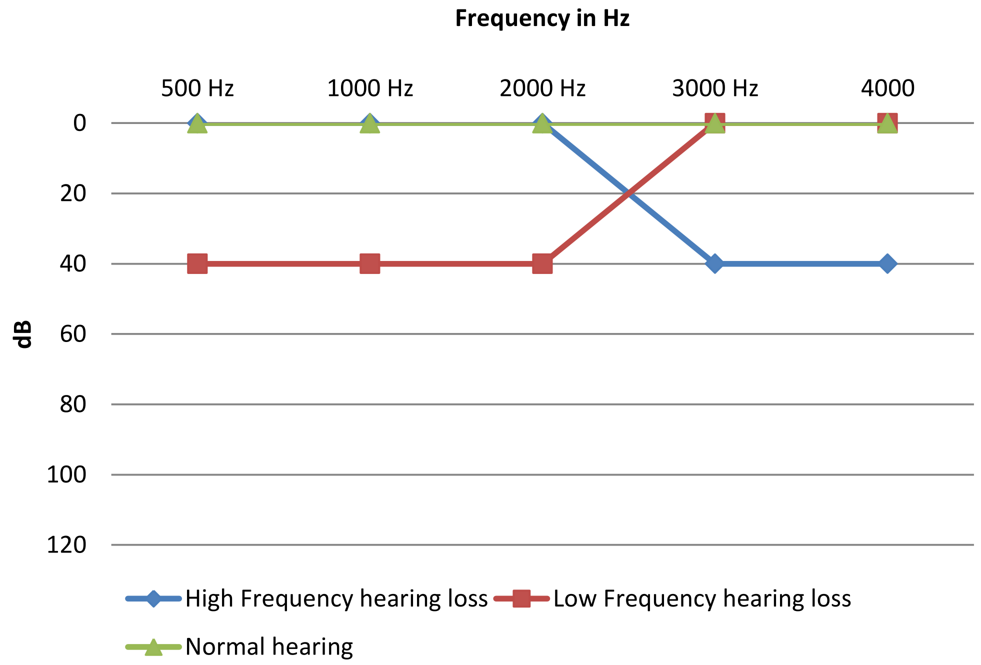


Contribution to PLH by hearing losses at 0,5 kHz

HTL in worse ear (dB)	4 Contribution to PLH by hearing loss at 0,5 kHz in better ear and given hearing loss at 0,5 kHz in worse ear																
	Hearing threshold level in better ear (dB)																
	≤15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	≥95
≤15	0,2																
20	0,4	0,6															
25	0,6	1,0	1,4														
30	1,0	1,4	2,0	2,8													
35	1,3	1,8	2,5	3,4	4,5												
40	1,7	2,2	3,0	3,9	5,1	6,4											
45	2,0	2,6	3,4	4,3	5,5	6,8	8,1										
50	2,3	2,9	3,7	4,7	5,8	7,1	8,4	9,7									
55	2,5	3,2	4,0	5,0	6,1	7,3	8,6	9,9	11,2								
60	2,7	3,4	4,2	5,2	6,3	7,5	8,8	10,0	11,3	12,6							
65	2,8	3,5	4,4	5,4	6,5	7,7	8,9	10,2	11,5	12,7	14,0						
70	2,9	3,7	4,5	5,5	6,6	7,8	9,1	10,3	11,6	12,9	14,2	15,5					
75	3,0	3,8	4,7	5,7	6,8	8,0	9,2	10,5	11,8	13,1	14,5	15,7	16,9				
80	3,1	3,9	4,8	5,8	6,9	8,1	9,3	10,6	12,0	13,3	14,7	16,0	17,2	18,2			
85	3,2	4,0	4,9	5,9	7,0	8,2	9,4	10,7	12,1	13,5	14,9	16,2	17,4	18,4	19,1		
90	3,4	4,1	5,0	6,0	7,1	8,3	9,5	10,8	12,2	13,6	15,0	16,3	17,6	18,5	19,2	19,7	
≥95	3,4	4,2	5,1	6,1	7,1	8,3	9,5	10,8	12,2	13,6	15,0	16,4	17,6	18,6	19,3	19,7	20,0

Figure 3-4 Instruction 171, PLH calculation table for 0,5 kHz (Source: COIDA, 2001, complete document included as Appendix C)

Based on calculations from these tables a low frequency hearing loss (0,5, 1 and 2 kHz) has a greater PLH value than a hearing loss in the high frequencies (3, 4 kHz). The following graph demonstrates the weighting of these calculation tables as well as the PLH value for 0 dB HL.



PLH values derived from calculation tables in Instruction 171:

PLH: 1,1 %

PLH: 2,2%

PLH: 7%

Figure 3-5 Audiogram (left and right ears identical) with 0 dB HL, high frequency hearing loss, and low frequency hearing loss and associated PLH values

Figure 3-5 demonstrates that a low frequency hearing loss of 40 dB HL has a PLH of 7% compared to the same degree of hearing loss in the high frequencies, revealing a PLH of 2,2%. Even with the absence of any hearing loss a PLH value of 1,1% is present. According to Instruction 171 compensation is paid out when a shift of 10% in PLH is present from any given audiogram and the baseline audiogram (done upon job engagement). Although NIHL is typically a high frequency hearing loss it seems that the low and mid frequencies are weighted more using the PLH calculation tables. This might be contributed to the fact that these frequencies are important for speech recognition in a quiet environment (Dobie, 2001) and compensation paid to people with occupational NIHL is focused on compensating for disability.

As part of hearing loss programmes the use of other diagnostic tests to identify NIHL have been recommended (Helleman & Dreschler, 2012; Helleman, Jansen, & Dreschler, 2010; Shupak, et al., 2007; Guida, De Sousa, & Cardoso, 2012; Attias, Bresloff, Reshef, Horowitz, & Furman, 1998). Because of the tests sensitivity to outer hair cell functioning (where noise damage first occur, see Chapter 2) these authors were specifically referring to Otoacoustic Emission testing (OAEs). OAEs and particularly the frequency specific distortion product OAEs (DPOAEs) have been described as an effective early indicator of cochlear damage because of noise exposure (Attias, et al., 1998). Results of recent studies have however also indicated that DPOAEs could be used on individual results but is not reliable on group results and thus OAEs have a limited applicability for monitoring the hearing status of an entire population (Helleman & Dreschler, 2012). It has also been shown that DPOAE results, although frequency specific, were not significantly correlated with pure tone audiometry and thus should not be used as an objective measure of pure-tone thresholds in early NIHL (Shupak, et al., 2007). For this study however, pure tone results have been used in analyses and it is beyond the scope of this study to investigate the utility value of OAEs as part of the hearing conservation test battery.

3.4.2. Contribution of age when calculating hearing impairment

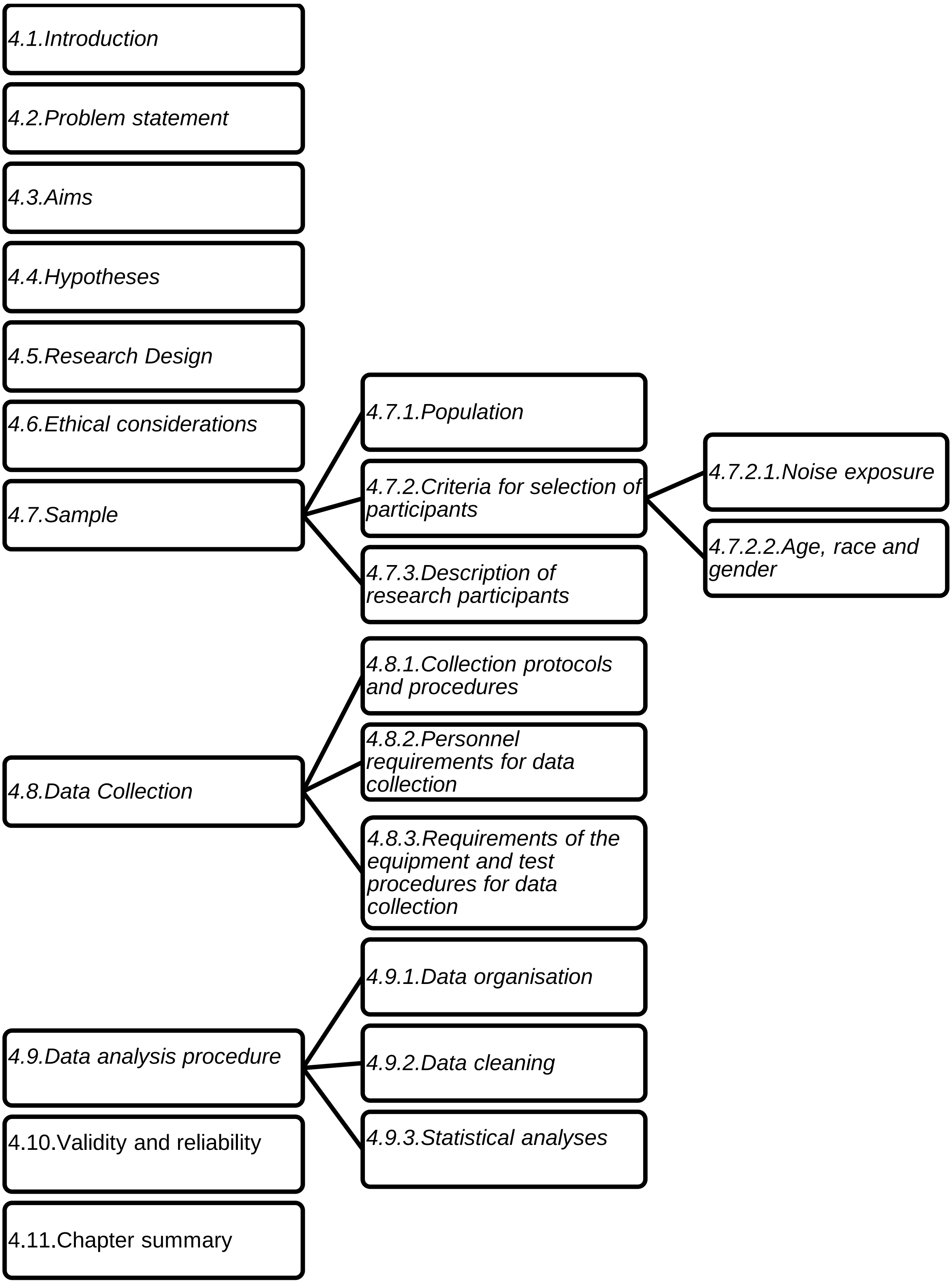
As discussed in chapter 2, hearing loss accompanies the aging process. It has been stated in literature that the effect of aging should be taken into consideration when hearing impairment is calculated (Dobie, 2001). Compensation of hearing loss is paid out to an individual who has acquired hearing loss because of the occupational noise he was exposed to. In the legal setting the company can be held liable for the damage caused to the hearing as a result of exposure to the occupational noise. It is therefore understandable that the effect of aging or another cause of hearing loss should be considered in the compensation process. Estimating hearing impairment regardless of the cause of the hearing loss or the audiometric configuration is a controversy often ignored or not made explicit (Dobie, 2001). In 1955 the AMA stated that an allowance should be made for the hearing loss with advancing age when hearing impairment is calculated (AMA, 1955). In 1971 Davis reasoned that hearing impairment should be calculated regardless of the cause of the impairment but that the relative contribution of different causes of hearing loss (such as noise or age) should be taken into consideration (Davis, 1971). This is referred to as allocation and can be defined as the process of determining the relative contributions of each cause to the individual’s hearing loss (Dobie, 2001, p. 282).

As compensation in South Africa is based on a shift in PLH from the baseline audiogram it seems straightforward if a single harmful event caused a large change in hearing as measured by the shift from baseline. In contrast age-related hearing loss and NIHL typically proceed simultaneously and show a decline in the high frequencies (Agrawal, et al., 2010). It might be argued that the baselining (bracketing) done in South Africa through the estimation of a shift in the PLH value is a way of apportioning pre-existing hearing loss to a previous employer(s), but not sensitive in identifying NIHL. “Age correction” (subtracting a certain decibel value based on a person’s age from the audiometric thresholds prior to estimating hearing impairment) has been proposed as a way to deal with this issue. In 1955 the AMA stated that the hearing impairment calculation/ formula should account for the hearing loss expected with advancing age (AMA, 1955). However, very few states in the United States of America (six of the 52 states) include correction for age in their hearing impairment calculations (Stander & Sataloff, 2006). Age correction has been criticised because the compensable hearing impairment might be “downgraded” below compensation level (Dobie, 2001). The AMA (2000) criticised age correction as fundamentally unfair because of the implication that all of the impairment is to be blamed on age-related hearing loss. Davis (1971) suggested that estimation of hearing impairment and allocation of relative contributions of NIHL and age-related hearing loss should be different processes. ‘Hearing handicap” should be calculated first, without taking into account the contribution of age to the hearing loss. Thereafter, using predictive data for presbycusis in non- noise-exposed populations the relative contribution of noise exposure to the hearing impairment can be estimated. Predictive data can be found in international standards such as the ISO 1990:1999 and ANSI S344 (1996). This approach has been used in studies to determine the burden and contribution of NIHL (Dobie, 1992; Dobie, 2005; Dobie, 1992; Agrawal, et al., 2010; Flamme, et al., 2011).

3.5. Summary and conclusion

In this chapter measurements of noise and the characteristics of noise constituting a hazard to hearing were discussed by giving a historical overview of noise definitions and measurements and describing the development of damage risk criteria. The research and surveys leading to the definitions of the level of noise exposure where risk to human hearing begins as well as the duration of noise exposure damaging to hearing were highlighted. Issues and controversies about the compensation of hearing impairment as well as formulae and calculations used for hearing impairment were deliberated. Finally the contribution of age when calculating hearing impairment was considered.

4. Methodology



4.1. Introduction

In the previous chapters a foundation of academic research was established. Different research into the field of noise-induced hearing loss (NIHL) was presented. The previous chapters aimed to frame NIHL within the context of research into the prevalence and incidence of NIHL worldwide. Research results highlighting the mechanism of NIHL and the co-variables that influence hearing were described. The effects of noise and damage risk criteria were also discussed and controversies were noted and deliberated. Within the framework of NIHL as a compensable disease, different definitions of hearing impairment were considered. The empirical part of this study set out to describe the prevalence and nature of NIHL and to evaluate the criteria for determining hearing impairment in South African gold miners.

Figure 4.1 depicts the research process followed throughout the study.

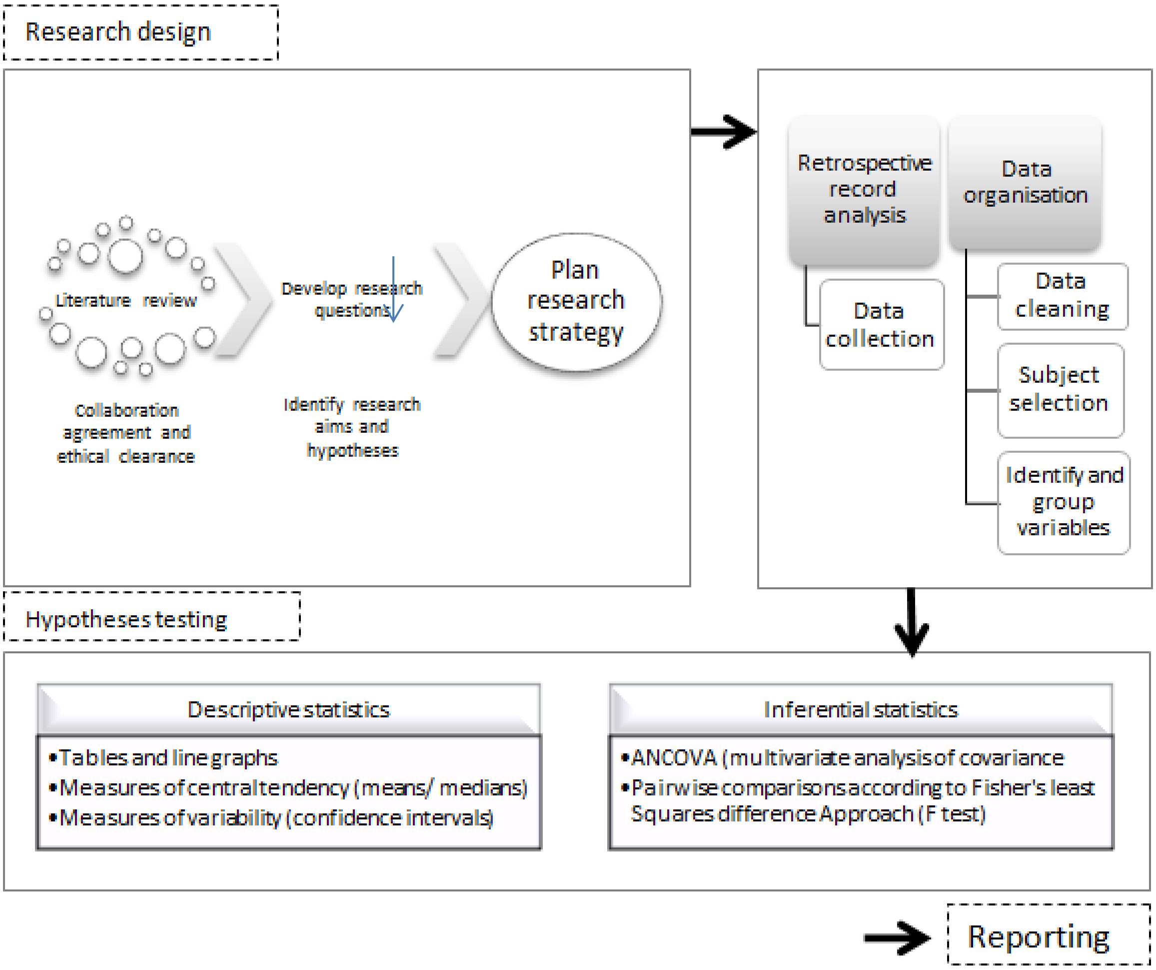


Figure 4-1 Research Design

4.2. Problem statement

In the previous chapters a foundation for academic research was established. Different aspects relating to noise-induced hearing loss (NIHL) were presented. Taking into account the dearth of research describing NIHL in large populations, differing opinions about the effect of variables (such as age, race and gender) co-existing with NIHL, many controversies surrounding the effect and measurement of noise, the calculation of hearing impairment, and the rate of hearing threshold deterioration in the mining community of South Africa, the research question shapes around what the nature and degree of NIHL is in a group of gold miners and whether the current criteria for characterising hearing impairment in South Africa is valid for identifying NIHL in gold miners.

The research questions that this study addresses are the following:

- What is the prevalence and degree of hearing loss in the group of gold miners?
- What is the prevalence and degree of hearing loss as a function of age, race and gender?
- What is the prevalence and degree of hearing loss as a function of occupation/ noise-exposure level?
- What is the combined effect of various biographical, environmental and work-related variables on hearing status?
- How effective is the sensitivity of the current impairment criteria to identify NIHL and compare it to other existing criteria?

4.3. Aims

The main aim of this study is to describe the prevalence and degree of NIHL considering demographic and environmental variables and to evaluate the criteria for determining hearing impairment in South African gold miners.

The following sub-aims have been formulated in order to realise the main aim of the study:

Sub aim one: To describe the prevalence and degree of hearing loss

Sub aim two: To describe the prevalence and degree of hearing loss as a function of age, race and gender

Sub aim three: To describe the prevalence and degree of hearing loss as a function of occupation / noise-exposure level

Sub aim four: To assess the combined effect of various biographical, environmental and work-related variables on hearing status

Sub aim five: To evaluate the effectiveness of the current impairment criteria to identify NIHL and compare it to other existing criteria

4.4. Hypotheses

In research literature the term “hypothesis” can either refer to a consequence of the research problem and as such a mere assumption, or it can refer to a statistical hypothesis that can be tested (Leedy & Ormrod, 2001). The statistical hypothesis can be defined as a predictive statement that relates an independent variable to some dependent variable, capable of being tested by scientific methods (Kothari, 1990). Statistical tests are designed to test a null hypothesis, which is a prediction that there will be no change (Brewer & Stockton, 2010). A null hypothesis is designated by H_0. An alternative hypothesis is the complement of the null hypothesis and would predict a direction of change or difference (Brewer & Stockton, 2010) (would be designated as H_1). Directional hypotheses for this study were formulated for hypotheses where the literature review indicated a specific direction (for aims 1, 2, 3, and 5).

The following hypotheses were formulated from the research aims (null hypothesis ($H_0 0$) or alternative hypothesis (H_a)):

$H1_0$	There is no difference between the prevalence and degree of hearing loss for the gold miners exposed to high levels of occupational noise and a control group.
$H1_a$	Gold miners exposed to high levels of occupational noise will have a higher prevalence and greater degree of hearing loss than a control group not exposed to occupational noise.
$H2i_0$	There is no difference between the prevalence and degree of hearing loss for gold miners of different ages.
$H2i_a$	Gold miners of greater age will have a higher prevalence and a greater degree of hearing loss than younger gold miners.
$H2ii_0$	There is no difference between the prevalence and degree of hearing loss for male and female gold miners.
$H2ii_a$	Male gold miners will have a higher prevalence of and a greater degree of hearing loss than their female counterparts.
$H2iii_0$	There is no difference between the prevalence and degree of hearing loss for gold miners of different races.
$H2iii_a$	White gold miners will have a higher prevalence and a greater degree of high frequency hearing loss than their black counterparts.
$H3_0$	There will be no difference in prevalence and degree of hearing loss as a function of occupation / noise-exposure level.
$H3_a$	Gold miners exposed to more occupational noise for a longer period will have a higher prevalence and a greater degree of hearing loss than participants exposed to lower levels of occupational noise.
$H4_0$	There will be no difference in degree of hearing loss as a function of different biographical, environmental or work-related variables.
$H4_a$	Hearing status will be influenced by different biographical, environmental or work-related variables.

$H5_0$ The current impairment criteria (RSA) are effective in identifying NIHL.

$H5_a$ The current impairment criteria (RSA) are not effective in identifying NIHL.

4.5. Research Design

The research design provides the logical structure that guides the investigation to address the research problems and answers the research questions (DeForge, 2010). Methodological decisions (such as data collection and data analyses) are informed and guided by the selected research design.

The research conducted for this study is exploratory and descriptive, utilising a non-experimental, observational design. Observational designs are referred to as non-experimental because the investigator does not intervene or manipulate variables (DeForge, 2010). Non-experimental research designs are grounded in an understanding of causal relations through observation, description and empirical testing (Maxwell & Satake, 2006).

A retrospective cohort design was used for the research conducted through this study. Cohort refers to any group of individuals with shared characteristics such as the same age, gender, occupational noise-exposure level or occupation. In a retrospective cohort design the investigator defines the sample population and collects data about both exposures and outcomes that have occurred in the past (such as the audiogram data used for this study, collected between 2001 and 2008) (DeForge, 2010; Ho, Peterson, & Masoudi, 2012). The data for this study were collected over a number of years by the occupational health department at the West Wits operation of the AngloGold Ashanti Gold Mine in the Witwatersrand. An advantage of such a retrospective study is that it is financially more feasible and can be completed in a shorter time frame (Maxwell & Satake, 2006) since past records with known outcomes are used. A retrospective design also made it possible to study an extremely large sample (Ho, Peterson, & Masoudi, 2012). A limitation of this retrospective cohort design was that the investigator did not have control over certain confounding variables. In order to control for the known confounding variables, such as age, statistical methods were employed and will be described in section 4.9.3.

Descriptive research involves attempting to define or measure a particular phenomenon, in this case hearing loss in gold miners (Dane, 1990). The research was exploratory in nature in order to determine whether a relationship existed among several variables under scrutiny. In this regard probability statistics that allow for the determination of test accuracy according to the proportion of all test results, both positive and negative, were used (Maxwell & Satake, 2006). The research was quantitative in nature. Quantitative research refers to the systematic empirical investigation of phenomena via statistical and mathematical techniques (Given, 2008). The objective of quantitative research is to develop and employ hypotheses pertaining to phenomena. The process of measurement is central to quantitative research because it provides the fundamental connection between empirical observation and mathematical expression of quantitative relationships (Given, 2008).

4.6. Ethical considerations

The guiding value for researchers is integrity, which is expressed in a commitment to the search for knowledge and in the honest and ethical conduct of research and dissemination and communication of results (MRC, 2002). The following ethical principles were adhered to during the course of the research project: the principle of respect and protection and the principle of scientific and academic professionalism (MRC, 2008).

Informed consent was obtained from the specific gold mine prior to the commencement of this project. Approval was obtained from the relevant authorities (attached as Appendix A). An agreement exists between the gold mine authorities and the mine workers that information on their hearing (audiograms and noise-exposure levels) may be used in possible research projects.

Information obtained in the course of this research study that revealed the identity of a participant or an institution was treated as confidential. Furthermore mineworkers' information (audiograms, work history and other relevant information) were used anonymously. A specific code was, where necessary, allocated to research participants for data processing and the names of participants were never used in data analyses or reporting.

In order to adhere to the principle of scientific and academic professionalism and accountability, the researcher did not fabricate data, misrepresent or intentionally mislead others in the nature of the findings. The researcher acknowledged the ideas, thoughts, words and works of others (Leedy & Ormrod, 2001).

Finally, concerning the motivation of this study, it can also be argued that the investigation of NIHL and possible contributing factors were ethically driven. Interventions based on scientific evidence are intrinsically more respectful of the principle of autonomy because in the absence of such evidence there can be no valid statements of benefits and harms that underlie informed choice (Hyde, 2005). Ethically there is also an obligation to maximise overall beneficence (relates to doing good) and non- malfeasance (relates to the avoidance of doing harm), and it is widely believed that scientific evidence is a more valid approach to that end than practices based on clinical intuition (Hyde, 2005).

4.7. Sample

4.7.1. Population

The population refers to the all-inclusive data set about which the researcher wishes to draw a conclusion (Maxwell & Satake, 2006). A sample is a subset of a population ideally drawn in such a way to be representative of the larger population (Dane, 1990). Statistical methods then allow the researcher to make inferences about the characteristics of a population on the basis of information obtained from that specific sample (Maxwell & Satake, 2006). In this study the population and sample can be viewed in two different ways.

Firstly the total group of gold miners in South Africa can be considered as the population under investigation. The specific group of gold miners from which the audiogram and other information were used is viewed as a sample of the total population. This method of sampling used is called stratified sampling, where the population is divided into sub groups called strata, in this case the specific mines

(Maxwell & Satake, 2006). This sampling method assures that certain segments of the population are adequately represented in the sample.

Secondly the population under investigation can be seen as the gold mine workers at the specific mines involved in this study. The audiological, biographical and environmental information of 57 714 mine workers (AngloGold Ashanti, 2007) were included in this sample. The sample included all the gold miners employed at two gold mine groups, consisting of seven different gold mines. Audiogram data collected after 2001 of all mine employees were used, as it became obligatory to do a baseline hearing test after 2001 according to Instruction 171 (RSA Department of Labour, 2001). According to the Mine Health and Safety Act and the Occupational Hygiene Regulations the mine employers are obliged to monitor the mine workers' hearing when persons are subjected to an occupational health hazard, i.e. an equivalent exposure level exceeding the limit of 85dB TWA (Franz & Phillips, 2001). Every gold miner had at least a baseline audiogram and an annual audiogram. The initial data made available for use comprised of 232 458 audiograms (baseline test results and subsequent annual hearing screening results). After data cleaning (see section 4.9.2) 171 441 audiograms were available for analysis. These were further reduced to the most recent audiogram per worker. Workers of all ages, across all genders and cultural groups as well as different exposure groups, were included.

Workers included as participants were defined in terms of specific exposure levels based on the noise measurements done by the occupational hygienists of the specific mines. Within these noise-exposure categories specific variables were used to further define the participants, such as the occupation of the mine worker (e.g. rock driller). The audiological and other biographical data of the total population of the participating mines were used. Data received from the mines however, did not include information regarding certain characteristics (such as age or race) of all participants. Only results of participants with this information available were used. As a consequence the complete sample of certain groups (such as white males in Noise Group 1) could not be used and the group for which data was available was used. Because of the very large sample size of the cohort (from which these purposive samples were selected), numbers of participants with the relevant information were still sufficient to do statistical analyses and statistical significance could be obtained.

Finally matched sampling was also used to select the participants for the different Noise Groups in order to detect a statistical significance between the groups that can be attributed to the influence of the independent variable (noise) (Maxwell & Satake, 2006). Variables such as age at test, type of noise exposure and length of noise exposure between the audiograms were matched within these three groups.

4.7.2. Criteria for selection of participants

Participants were selected according to set criteria to increase internal validity and to control the effect of variables on the hearing of the gold miners. Selection criteria included exposure to hazardous occupational noise either underground, on surface or no known occupational noise exposure, the type of noise exposure (based on the homogenous exposure group), race and gender. Data were selected from audiometric and noise measurement records of the participants, made available by the mine’s occupational health department. Data categories in the original dataset included the following information: a company number, audiogram test dates, audiogram test times, type of audiogram, user code, thresholds for the air conduction frequencies at 0.5, 1, 2, 3, 4, 6, 8 kHz in both the left and right ear, schilling action and period, audiometer location, audiometer make, audiometer model, audiometer serial, audiometer calibration date, job description (company, responsibility, department, activity, section, designation, position), percentage binaural impairment (PBI), percentage monaural impairment left (PMIL), percentage monaural impairment right (PMIR), percentage loss of hearing (PLH), PLH shift, gender, race, initials, title, surname, company name, place name, ID number, passport number, passport country number, last referral date, last reported date, training date, last compensation date, date of birth. Not all these categories had data included for participants. The data that were used, either as it had been presented in the document or to deduce other information (such as age at test), were the following: a unique number per participant, audiogram test dates, type of audiogram, thresholds for the air-conduction frequencies at 0.5, 1, 2, 3, 4, 6, 8 kHz in both the left and right ear, job description, percentage loss of hearing (PLH), gender, race, ID number.

4.7.2.1. Noise exposure

Participants were selected according to their current exposure level to workplace noise. Exposure levels were described in terms of a specific occupation, as specific occupations are matched with different exposure levels, e.g. pneumatic rock drill equals ~108 dB (A) (Phillips, et al., 2007). The different exposure levels/occupations were then categorised in 4 groups namely: 1) above surface noise exposure (≥85 dB A), 2) below surface noise exposure (≥85 dB A), 3) no know occupational noise exposure and 4) uncertain levels of noise exposure e.g. students and trainees. Surface noise sources include conveyor belts, crushers and transportation equipment (Hessel & Sluis-Cremer, 1987). Underground sources of high noise levels include rockdrills, ventilation fans, transportation equipment and explosive blasts (Hessel & Sluis-Cremer, 1987). Blasting and drilling underground differ from that on the surface, being influenced by mine geometry, openings and friction from wall roughness. As with other impulsive exposures, the cumulative effect on mine workers is unclear (McBride, 2004). The levels of noise exposure were not documented in the audiogram data files. Based on dosimeter data received from the mine's noise hygienist (per occupation) the occupational groups were divided into different groups. Many of the occupations, however, had no noise data available and the classification of these occupations into the four Noise Groups was undertaken by the occupational medical examiner and the noise hygienist. Sub groups (e.g. Noise Groups 1) were compared to other sub groups (No Noise Group). In order to narrow the analysis down and to use a group with homogenous noise exposure (referred to as homogenous exposure groups (HEG) at the mine where participants work), two alternative sub groups were also analysed and compared within the three groups i.e. drillers (high levels of noise exposure) vs. administration workers (no known noise exposure).

Years of exposure were also taken into account by stratifying participants into different working year groups (based on the years of exposure to occupational noise). These working years were not available from the data set received from the mine. Combining different data sets, using individual employment numbers allocated to workers made it possible to calculate working years based on information about the date engaged (at work) and the date of the most recent audiogram. This data were not available for all participants and made stratification into working years possible for only a limited number of participants.

4.7.2.2. Age, race and gender

Because of the many similarities and interactions between NIHL and age-related hearing loss (ARHL) it is imperative to take into account the contribution of ARHL when determining the effect of noise on hearing (Ciletti & Flamme, 2008; Niskar, et al., 2001; Pyykkö, Toppila, Zou & Kentala, 2007; Dobie, 2001; Hoffman, Dobie, Ko & Themann, 2010; Flamme, et al., 2011). Participants were stratified into different age groups namely: 16 to 30 years, 31 to 40 years, 41 to 50 years, 51 to 60 years and 61 to 65 years. For sub aim 4 however, to assess the combined effect of various biographical, environmental and work-related variables on hearing status, data were compared to data from the available criteria standards (ISO, 1990; ANSI, 1996). In order to compare age groups participants were also classified in the age categories used by these standards namely 25 to 34 years, 35 to 44 years, 45 to 54 years and 55 to 64 years. Finally participants were classified according to their gender (male or female) and their race (black or white).

4.7.3. Description of research participants

The following tables and graphs serve to describe the research participants and their respective divisions into different groups and categories and the number of participants in each group.

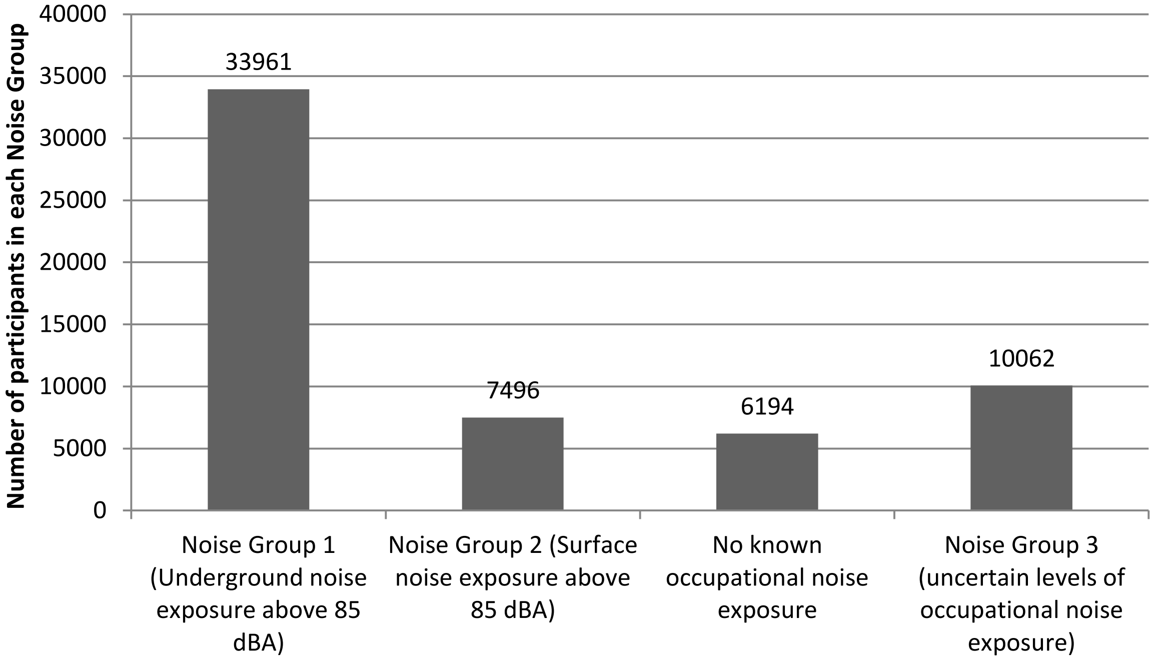


Figure 4-2 Number of participants categorised into the different Noise Groups $(\boldsymbol{N_{total} = N_{Noise\ Group\ 1} + N_{Noise\ Group\ 2} + N_{No\ Noise\ Group} + N_{Noise\ Group\ 3} = 57713})$

Figure 4.1 shows the numbers of participants in each Noise Group. Noise Group 1 (underground noise exposure ≥85 dB A) had the most participants, followed in numbers by Noise Group 3. Because the noise exposure of participants in this group was uncertain (either job descriptions were unclear, such as “trainee”/ “consultant”, or no data on noise exposure was available for the specific job description), analysis of the data for this Noise Group was not done.

Table 4-1 Number of participants for each occupation (labelled by the mine) constituting each Noise Group.

$$(N_{total} = N_{Noise\ Group\ 1} + N_{Noise\ Group\ 2} + N_{No\ Noise\ Group} + N_{Noise\ Group\ 3} = 57713)$$

Noise Group occupations	N	Noise Group occupations	N	Noise Group occupations	N	Noise Group occupations	N
Noise Group 1 (Underground noise exposure >85 dB A)	**33961**	**Noise Group 2 (Surface noise exposure >85 dB A)**	**7496**	**No Noise Group (No known noise exposure)**	**6194**	**Noise Group 3 (Unknown occupational noise exposure)**	**10062**
AQUAJET OPERATOR	61	ACCLIMATISATION	1	ACCOUNTS	117	WED	24
BACKFILL	5	BLACKSMITH	1	ADMIN	2211	AIR QUALITY ANALYST	4
BANKSMAN-	70	BUILDER	34	ANALYST	69	APTITUDE TESTING	1
BELL RINGER	1	BULLDOSER	1	BIOLOGICAL TESTING	6	ASSISTANT	5
BELTSMAN	26	CARPENTER	54	BUYER	2	BARRIER	3
BLASTER	1	CRANE DRIVER	18	CHANGE HOUSE	17	BATTERY	5
BOILERMAKER	926	CREW BOSS	6	CLAIMS	1	CABLE	1
BORE OPERATOR	1	CREW LEADER	19	CLEANER	1008	COMPRESSOR DRIVER	14
BOX CONTROLLER	76	DEVELOPER	19	COMMERCIAL	67	CONSTRUCTION	3475
CENTRIFUGE OPERATOR	106	DIESEL MECHANIC	22	COMMUNICATION	6	CONTRACTOR	149
CONVEYANCE OPERATOR	917	DRIVER HEAVY DUTY	402	COOK	628	CONTROL ROOM	13
CREW BOSS	21	DRIVER LIGHT	2	DESIGNER	22	CONTROLLER	77
CREW LEADER	1626	DRIVER TRAIN	1	DRIVER CAR	20	DOMAIN	48
CUTTER	2	ELECTRICIAN	76	ENVIRONMENTAL	43	DRAUGHTING	3
DEVELOPER	187	ENGINEERS	327	HOSTEL	26	DRAUGHTSPERSON	1
DIESEL MECHANIC	16	FITTER AND TURNER	103	INCAPACITATED	11	ENGINEER	5
DRILLER	4399	FOREMAN	85	INSPECTOR	4	ESTIMATOR	3
DRIVER TRAIN	3	FRIDGE PLANT	27	INSTRUCTOR	54	EVALUATION	4
ELECTRICIAN	666	GANG SUPERVISOR	4	INSTRUMENTS	6	EVALUATOR	13
ENGINEER	1815	GARDEN SURFACE	94	INVENTORY	5	FACILITATOR	1
ESH	2	GARDEN SURFACE LAWNMOWER	2	LAB	46	FIRE PATROLMAN	4
EXPLOSIVES	1	GROUTING	18	LAB TECHNICIAN	1	GEOLOGICAL	26
FITTER AND TURNER	818	LAUNDRY	3	LAMP REPAIRER	64	GEOLOGIST	13
FOREMAN	354	LEADER	2	LOGISTICS	20	GEOLOGY	4
GANG SUPERVISOR	12	LOADER	56	MANAGER	521	GLAZER	1
GRINDER OPERATOR	1	MACHINE	170	PAINTER	69	GOLD LOSS	5
GROUTING	111	MESH AND LACING	2	PANEL COORDINATOR	18	GRADE OFFICER	6
HOIST DRIVER	1	METALLURGY	5	PLANNING	1	GRADUATE	124
LEADER	20	MINE CAPTAIN	26	PROCESS LEADER	2	HANDYMAN	13
LOADER	399	MINER	423	PROCUREMENT	1	HELPER	5
LOCO DRIVER	1888	ONSETTER	18	PRODUCTION	3	HYDROLIC R/BREAK	1

Noise Group occupations	N	Noise Group occupations	N	Noise Group occupations	N	Noise Group occupations	N
Noise Group 1 (Underground noise exposure >85 dB A)	**33961**	**Noise Group 2 (Surface noise exposure >85 dB A)**	**7496**	**No Noise Group (No known noise exposure)**	**6194**	**Noise Group 3 (Unknown occupational noise exposure)**	**10062**
MACHINE	662	PIPES AND TRACKS	1	RADIATION	3	LABOURER	644
MESH AND LACING	5	PLANT ATTENDANT	183	RECREATION	1	LASHER	22
METALLURGY	7	PLANT CREW	16	RESOURCE MANAGER	9	LEARNER	18
MINE CAPTAIN	203	PLATE LAYER	1	SALES	1	MAINTENANCE	38
MINER	2730	PLATER AND WELDER	2	SALVAGE WORKER	7	MASON	11
MINER BLASTER	11	PLUMBER	18	SAMPLING	143	MATERIALS	1
MONO WINCH DRIVER	4	PUMP ATTENDANT	17	SANITATION CREW	48	MECHANIC	44
ON SETTER	251	RAISE BORE OPERATOR	1	STAGE HAND	5	MEDICAL	731
PIPES AND TRACKS	15	REFRIGERATION PLANT	32	STORE	172	MESSENGER	1
PLANT ATTENDANT	161	RIGGER	14	STRATA CONTROL	4	NOZZLE OPERATOR	2
PLANT CREW	16	SCALAR OPERATOR	1	STUDENT	1	OFFICER	1
PLATE LAYER	1	SCRAPER WINCH OPERATOR	403	SWEEPER	2	OPERATOR	278
PLATE LAYER UNDERGROUND	1	SHIFT BOSS	26	SWITCHBOARD OPERATOR	1	PORTER	19
PLUMBER	7	SLIMES	6	SYSTEMS CONTROLLER	12	PUNCH OPERATOR	5
PRINTING PRESS OPERATOR	1	STEEL FIXER	11	TIMEKEEPER	5	QUALITY CONTROL	2
PUMP ATTENDANT	1	STEEL RECONDITIONER SURFACE	19	TRAINING	615	RAIL TRACKS	5
PUMP ATTENDANT	212	SUPPORT	5	TRANSPORT	93	RECEIVER	3
RAISE BORE OPERATOR	18	SURFACE	2688	WAREHOUSING	3	REDUCTION	13
RE-FRIDGERATION PLANT	13	SURFACE DRILLER	3				
RIGGER	121	SURVEY	1				
RUBBER LINING	1	TEAM LEADER, SURFACE	601				
SCALAR OPERATOR	1	TEAM MEMBER, SURFACE	51				
SCOTT WINCH DRIVER	1	TIMBERING	159				
SCRAPER	1000	WASTE DISPOSAL	1				
WINCH OPERATOR	222	WELDER	208				
SHIFT BOSS	1304	WINCH DRIVER	28				
SHOTCRETTING	76	WINDING ENGINE DRIVER	566				
SHUTTERHAND	5	WIRE MESHER	76				
SINKER	17	YARDMAN	11				
STEEL FIXER	2						
STEELRE-CONDITIONER UNDERGROUND	16						

Noise Group occupations	**N**	**Noise Group occupations**	**N**	**Noise Group occupations**	**N**	**Noise Group occupations**	**N**
Noise Group 1 (Underground noise exposure >85 dB A)	**33961**	**Noise Group 2 (Surface noise exposure >85 dB A)**	**7496**	**No Noise Group (No known noise exposure)**	**6194**	**Noise Group 3 (Unknown occupational noise exposure)**	**10062**
STOPE	4323						
STOPE DRILLER	6						
STOPE LASHER	3						
SUPPORT	35						
SURVEY	5						
TEAM LEADER	1462						
TEAM MEMBER	109						
TIMBERING	97						
UNDERGROUND	1081						
UNDERGROUND ASSISTANT	820						
UNDERGROUND BANKSMAN	46						
UNDERGROUND ELECTRICIAN	11						
UNDERGROUND HANDYMAN	1						
UP GRADER	4						
VAMPING	80						
VENTILATION	42						
VOID FILLING	12						
WATER JET OPERATOR	321						
WINCH	1082						
WINCH DRIVER	261						
WINCH OPERATOR	2554						
WINCH TRANSPORTER	2						

Table 4.1 shows that 234 unique occupations were labelled by the mine and allocated to participants in the audiogram data set. Most of these occupations are done underground and workers are exposed to ≥ 85 dB A occupational noise.

In order to aid comparison between different noise-exposed groups two sub groups from Noise Group 1 and the No Noise Group were also selected for comparison. These are the drillers and the administration personal (marked in grey in table 4.1). Based on data received from the mine’s noise hygienist (personal dosimeter measurements) drillers in these specific mines are exposed on average to 140 dB A noise (minimum 129.4 dB A and maximum 158.5 dB A). Participants doing administration work are not exposed to any known occupational noise. The numbers of participants in these two HEGs were 2 211 participants in the Administration Group and 4 399 participants in the Driller Group.

Table 4.2 shows the breakdown of participants in the different Noise Groups into different age categories as described in section 4.4.2.2.

Table 4-2 Number of participants categorised into different age categories per Noise Group (Total N=57713)

Age categories	Number of participants	Age categories	Number of participants
Noise Group 1 (Underground noise exposure >85 dB A)	**Total N=33961**	**No Noise Group (No known noise exposure)**	**Total N=6194**
16 to 30yrs	7568	16 to 30yrs	1623
31 to 40yrs	11190	31 to 40yrs	2327
41 to 50yrs	11058	41 to 50yrs	1696
51 to 60yrs	3683	51 to 60yrs	492
61 to 65yrs	250	61 to 65yrs	24
Age categories	**Number of participants**	**Age categories**	**Number of participants**
Noise Group 2 (Surface noise exposure >85 dB A	**Total N= 7496**	**Noise Group 3 (Unknown occupational noise exposure)**	**Total N=10062**
31 to 40yrs	2257	31 to 40yrs	2261
16 to 30yrs	1824	16 to 30yrs	2839
41 to 50yrs	2245	41 to 50yrs	2712
51 to 60yrs	1047	51 to 60yrs	2035
61 to 65yrs	83	61 to 65yrs	141

For the HEGs, driller and administration, the number of participants per age group is shown in figure 4.2 below.

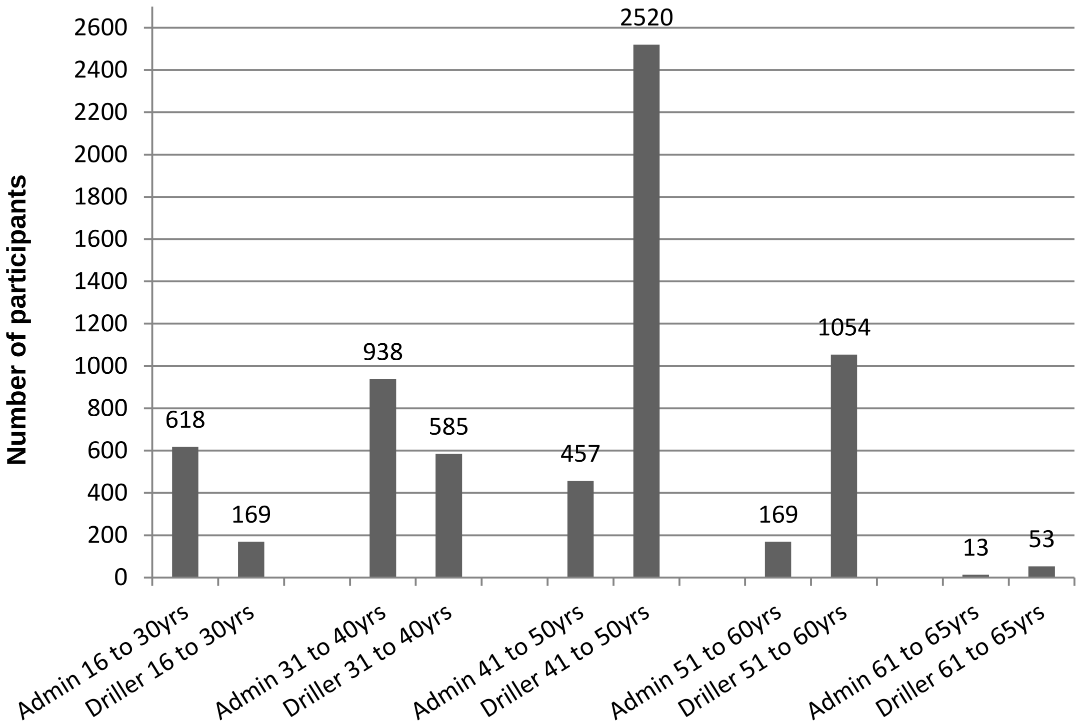


Figure 4-3 Number of participants in each age category for the Driller and Administration groups ($\boldsymbol{N_{Admin} = 2211;\ N_{Driller} = 4399}$)

Participants were further divided into different gender and race groups. Information on the gender and race of participants were not available for all participants and the addition of numbers for the different categories do not amount to the total number of participants.

Table 4-3 Number of participants categorised into different age categories and race groups (white and black) per Noise Group

Noise Groups/ Age categories/ Black (B)/ White (W)	Number of participants	Noise Groups/ Age categories/ Black (B)/ White (W)	Number of participants
Noise Group 1 (Underground noise exposure >85 dB A)	$N_{Noise\ Group\ 1}$ =33961	No Noise Group (No known noise exposure)	$N_{No\ Noise\ Group}$ =619
16 to 30yrs	$N_{16-30yrs}$ =7568	**16 to 30yrs**	$N_{16-30yrs}$ =1623
B	6192	B	1301
W	1340	W	303
31 to 40yrs	$N_{31-40yrs}$ =11190	**31 to 40yrs**	$N_{31-40yrs}$ =2327
B	9739	B	1937
W	1361	W	363
41 to 50yrs	$N_{41-50yrs}$ =11058	**41 to 50yrs**	$N_{41-50yrs}$ =1696
B	9570	B	1405
W	1410	W	267
51 to 60yrs	$N_{51-60yrs}$ =3683	**51 to 60yrs**	$N_{51-60yrs}$ =492
B	2902	B	377
W	754	W	104
61 to 65yrs	$N_{61-65yrs}$ =250	**61 to 65yrs**	$N_{61-65yrs}$ =24
B	154	B	11
W	94	W	12
Noise Group 2 (Surface noise exposure >85 dB A)	$N_{Noise\ Group\ 2}$ =7496	Noise Group 3 (Unknown occupational noise exposure)	$N_{Noise\ Group\ 4}$ =10062
16 to 30yrs	$N_{16-30yrs}$ =1824	**16 to 30yrs**	$N_{16-30yrs}$ =2839
B	1485	B	2339
W	316	W	470
31 to 40yrs	$N_{31-40yrs}$ =2257	**31 to 40yrs**	$N_{31-40yrs}$ =2261
B	1873	B	1955
W	345	W	286
41 to 50yrs	$N_{41-50yrs}$ =2245	**41 to 50yrs**	$N_{41-50yrs}$ =2712
B	1849	B	2431
W	375	W	262
51 to 60yrs	$N_{51-60yrs}$ =1047	**51 to 60yrs**	$N_{51-60yrs}$ =2035
B	777	B	1849
W	259	W	174
61 to 65yrs	$N_{61-65yrs}$ =83	**61 to 65yrs**	$N_{61-65yrs}$ =141
B	59	B	114
W	24	W	27

In table 4.4 the number of participants per race group for the Driller and Administration groups is shown.

Table 4-4 Number of participants in the Driller and Administration Groups in the different race groups (black and white)

DRILLER	$N_{Driller} = 4399$	ADMIN	$N_{Admin} = 2211$
B	4096	B	1885
W	287	W	293

Table 4.5 shows the number of participants per Noise Groups in the different race (white and black) and gender groups. As noted earlier, information on the gender and race of participants was not available for all participants and the addition of numbers for the different categories does not amount to the total number of participants.

Table 4-5 Number of participants in each Noise Group, categorised by race and gender

Noise Group/ Race group (black/ white)/ Gender (female/male)	Number of participants	Noise Group/ Race group (black/ white)/ Gender (female/male)	Number of participants
Noise Group 1 (Underground noise exposure >85 dB A)	$N_{Noise\ Group\ 1} =$ **33961**	**No Noise Group (No known noise exposure)**	$N_{No\ Noise\ Group} =$ **6194**
Black	**28724**	**Black**	**5053**
Female	849	Female	314
Male	17933	Male	2790
White	**4987**	**White**	**1056**
Female	217	Female	42
Male	2687	Male	508
Noise Group 2 (Surface noise exposure >85 dB A)	$N_{Noise\ Group\ 2} =$ **7496**	**Noise Group 3 (Unknown occupational noise exposure)**	$N_{Noise\ Group\ 4} =$ **10062**
Black	**6064**	**Black**	**8735**
Female	398	Female	459
Male	4388	Male	5876
White	**1336**	**White**	**1239**
Female	211	Female	157
Male	783	Male	688

4.8. Data Collection

4.8.1. Collection protocols and procedures

In terms of the Mine Health and Safety Act (Department of Minerals and Energy, 1996), Instruction 171 (COIDA, 2001) and South Africa National Standards (SANS10083:2007, 2007) the employer is obliged to establish and maintain a system of medical surveillance for all employees in any working place where the equivalent, continuous A-weighted sound pressure level, normalised to an 8 hour working day or a 40 hour working week exceeds 85 dB (A). Legislation (Instruction 171) made it compulsory that a baseline audiogram is conducted for all individuals within two years after this legislation had been published and within 30 days for new employees who had not worked previously. The mine concerned in this study complied with these regulations and therefore audiograms from the year 2001 onwards until 2008 were used.

Data consist of hearing tests (audiograms) of the gold miners at the three different mines (Tautona, Savuka and Mponeng) at AngloGold Ashanti. The occupational medical/health department accessed the mine’s electronic database and exported all required information to Microsoft Excel 2007 worksheets. The audiometric records consisted of pure-tone air-conduction audiograms for right and left ear respectively. Some audiograms were obtained from a diagnostic evaluation, other from a baseline, periodic screening, monitoring or exit assessment. These audiograms have been obtained at the mines involved in this study by mining personnel and comprise the following frequencies: 0.5, 1, 2, 3, 4, 6 and 8 kHz. Another set of data that was used for this study is the percentage loss of hearing (PLH). This value was extracted from the mine’s audiometric database and is calculated for each set of audiometric data. The PLH forms the principal criterion for assessing hearing status for compensation claims. Shifts in PLH are identified by comparing current values with that from the baseline audiogram (for cumulative shifts) or previous audiograms (for interim shifts) (COIDA, 2001). PLH is derived from combining the individual’s hearing threshold levels at 0,5; 1; 2; 3 and 4 kHz, using tables from Instruction 171 (COIDA, 2001). A shift of ten per cent or more in PLH, as compared with the baseline audiogram, has been accepted as the level at which a compensation claim may exist (COIDA, 2001). In all cases where PLH values exceeded 10% diagnostic hearing test results were available. Where PLH values were below 10% baseline testing or screening results were used (see table 4-6 below for description). The following information was also gathered from the available database: Age of the miners, occupation (was classified according to the noise-exposure level), years of service in the different working environments, race and gender.

Audiometry for this study was conducted in a soundproof room that complied with the relevant requirements for background noise and environmental conditions stipulated in the South African National Standards (SANS) document (SANS10154-1:2004, 2004; SANS10154-2:2004, 2004). This standard provides background noise limits for air-conduction, bone-conduction and sound-field audiometry. Audiometry was conducted at the specific mines according to the specifications set out in Instruction 171 (RSA, Department of Labour, 2001).

The following table from the handbook of occupational health practice in the South African mining industry (Franz & Phillips, 2001) summarises the application, purpose and procedural requirements for audiometric testing of mine workers. These requirements were adhered to by mining personnel when audiogram data for the study were collected.

Table 4-6 Definition and requirements for audiometry as required by the gold mines under investigation, its application, purpose and procedural requirements (Franz & Phillips, 2001)

Type of audiometry	Application	Purpose	Procedural requirements
Baseline (Code 3)	Before allocation to work in a noise zone (TWA ≥85 dB A) or 30 days of commencing such work	To provide a reference for evaluating any future changes in hearing status	Before testing, a 16-h period with no exposure to noise ≥85 dB A (use of HPDs complying with SANS 10083:2007, II or III is NOT acceptable); use better of the two audiograms that are within 10 dB at 0,5; 1; 2; 3 and 4 kHz; where consistency is not possible or pathology is suspected, refer for medical opinion to consider possible audiologist or specialist evaluation; incorporate results into medical surveillance records.

Type of audiometry	Application	Purpose	Procedural requirements
Periodic screening **(Code 1)**	Annually for noise-exposed individuals (TWA ≥85 dB A)	To quantify any permanent hearing loss that results from exposure to noise	Before testing, a 16-h period with no exposure to noise, ≥85 dB A (use of HPDs complying with SANS 10083:2004, II or III is acceptable); incorporate results into medical surveillance records
Monitoring **(Code 2)**	6-Monthly for high-risk exposure (TWA ≥105 dB A), participant to employer's code of practice	To identify temporary threshold shifts and enable the prevention of permanent hearing loss; to evaluate the efficacy of HPDs	Conduct testing as soon as possible after exposure to noise, i.e. at the end of the working shift
Exit **(Code 6)**	On conclusion of employment in a noise zone (TWA ≥85 dB A) or on employee's termination	To provide a record of hearing levels on conclusion of employment in a noise zone	Before testing, a 16-h period with no exposure to noise, ≥85 dB A (use of HPDs complying with SANS 10083:2004, II or III is acceptable); incorporate results into medical surveillance records
Diagnostic **(Code 5)** **Compensation** **(Code 4)**	When medical opinion recommends a specialist evaluation for purpose of investigating ear pathology, inconsistent baseline results or a potential compensation claim for NIHL	To enable a specialist evaluation of hearing status as required; to support a possible compensation claim, where indicated	Before testing, a 16-h period with no exposure to noise ≥85 dB A (use of HPDs complying with SANS 10083:2004-I, II or III is NOT acceptable); to determine eligibility for compensation, two audiograms must be recorded during two different sittings (both may be on the same day). If the two differ by more than 10 dB for either ear at any mandatory test frequency (0,5; 1; 2; 3; 4; 6 or 8 kHz), a third audiogram must be recorded during a third sitting. Where the third audiogram also indicates inconsistencies >10 dB, participant should be re-evaluated in six months' time. Thereafter, if inconsistent results are still not obtainable, participant may be referred for further specialist evaluation of hearing loss; incorporate results into medical surveillance records

(Source: Handbook of Occupational Health Practice in the South African Mining Industry (Franz & Phillips, 2001))

4.8.2. Personnel requirements for data collection

The baseline, periodic screening, monitoring and exit audiograms were conducted by personnel (audiometrists, occupational medical personnel, audiologists and medical practitioners specialising in otorhinolaryngology) who had been registered with the Health Professions Council of South Africa whereas the diagnostic audiometry was conducted by audiologists and medical practitioners specialised in otorhinolaryngology registered with the Health Professions Council of South Africa (Franz & Phillips, 2001).

4.8.3. Requirements of the equipment and test procedures for data collection

The audiometer used in the screening set-up at the occupational health facility of West Wits is the Tremetrics RA 600 Type 4 audiometer (serial no 971499) with TDH 39 headphones. Up to ten workers can be tested simultaneously using the audiometer's automatic testing procedure and specifically designed software (Everest). This allows for automatic and simultaneous testing of more than one client at a time, as well as saving the information to a database. Diagnostic testing is conducted in another facility by using the GSI 61 audiometer (serial no AA041138).

Acoustic enclosures or soundproof rooms for audiometric testing comply with the requirements for background noise and environmental conditions specified in SANS 10083:2007.

The following audiometer calibration and verification requirements were met (Guild et al. 2001):

- Screening and diagnostic audiometers had valid calibration certificates at the time of the commissioning of this study (see Appendix D – calibration certificate).
- Calibration service providers had the necessary training and equipment, and demonstrate traceability to the National Acoustic Standard. Calibration is annually done by ACTS, Audiometric Calibration and Training Services.

- Personnel conducting audiometry validated the accuracy and calibration continuity of audiometers on a weekly basis by means of subjective or biological calibration checks. These records are retained for record-keeping.

- Each day, prior to testing, the personnel conducting audiometry confirmed the correct functioning of the audiometer, inspected all cables and connections, confirmed the proper functioning of the patient's response button, and performed a listening check to ensure the absence of unwanted sounds.

Audiometric testing procedures included clear instructions prior to testing and a familiarisation phase to confirm participant competence by observing responses to preliminary test signals (Franz & Phillips, 2001). This is followed by the test phase during which hearing threshold levels are measured and recorded. The ascending test method (according to ISO 6189) is recommended (Franz & Phillips, 2001).

4.9. Data analysis procedure

In this retrospective study, relevant data were extracted from the gold mine's database (Everest) and imported to a software programme (Microsoft Excel 2007 and 2010) to aid analysis of the data**.**

4.9.1. Data organisation

The following information was gathered from the available database: Age of the miners, occupation (classified according to the noise-exposure level), years of service in the different working environments and gender. Audiometric data were organised using the audiometric frequencies tested (thus decibel (dB) hearing- level (HL) threshold values per frequency) per ear, binaural averages and the PLH values. Data were transferred to a Microsoft 2007 and 2010 Excel worksheet format from where it was transferred to a statistical analysis programme.

In order to answer the aims set out as research aims one to four, audiogram data were used. The Everest data set had limited data available on the employee's gender, race and engage date (date that work commenced). Thus another information data set was used and combined by using each participant’s unique employee numbers. In order to aid comparison each participant was then awarded a new number in numerical order. This data used involved a dB HL value at each frequency (0,5; 1; 2; 3; 4; and 6/8 kHz) for each participant for the left and right ears. Using these values (in dB HL) a high frequency average (HFA) for frequencies 3,4 and 6 kHz for each ear were calculated and also a binaural average HFA (HFA346). The same was done with the low frequency average (0.5, 1, 2 kHz). Each participant had a LFA512 binaural and for the left and right ears. The reason for analysing the lower and higher frequencies separately was to be able to make a more specific comparison between the low and high frequencies, due to the fact that noise and age have a greater influence on the higher frequencies (Sliwinska-Kowalska et al., 2006), while for example the PLH’s weighing is highest for hearing loss at 1 kHz and lowest for hearing loss at 4 kHz (Guild et al., 2001). Another reason for choosing this specific high frequency category is that Girard et al. (2009) reported that the severity of hearing impairment at 3, 4 and 6 kHz (average bilateral hearing-threshold levels exceeding a 15 dB of hearing loss), is increasing the risk for work-related accidents. Hearing loss categories were also calculated using the available thresholds data and this was organised in the hearing categories proposed by Yantis (Yantis, 1994). The following table summarises these hearing loss categories:

Table 4-7 Hearing threshold categories based on the degree of impairment proposed by Yantis (1994) and used by Picard (2008) and Girard (2009)

Category of hearing sensitivity	Per frequency Per hearing threshold average for high frequencies (3, 4, 6 kHz) (HFA346) Per hearing threshold average for low frequencies (0.5, 1 and 2 kHz)(LFA312)
Normal hearing	0-15 dB
Just noticeable hearing loss	16 to 30 dB
Mild hearing loss	31 to 40 dB
Moderate hearing loss	41 to 50 dB
Severe hearing loss	≥51 dB

From table 4.7 it is clear that these hearing loss categories are conservative compared to other criteria (Jerger, 2009). Based on the data from a large scale study

(N=53000) (Picard, et al., 2008), Picard (2012) suggests that within the context of NIHL, Yantis' low fence at 16 dB HL appears to be a sensible cut-off point to decide on the presence of some minimal degree of hearing loss. Furthermore, the distribution of their data showed only a few outliers beyond the 60 dB HL mark. As a whole, their data indicate that the Yantis classification may be a finer grain scale to represent NIHL (Picard, 2012).

In order to reach the aims set out as research aims, values that were used for statistical analyses also included the PLH (as calculated through the use of the calculation tables of Instruction 171), as well as other calculations used to determine hearing impairment such as the method of the AMA (Dobie, 2001). PLH values were used to divide participants into different PLH categories. The AMA values were calculated based on the AMA formulae (AMA, 2001), using an average of thresholds at 0.5, 1, 2 and 3 kHz in both ears, subtracting the low fence of 25dB from the average, and multiplying the value with 1,5%. The value of the best ear is then multiplied by five and the value of the worst ear is added to that, the total divided by 6 (better ear weighted 5:1) to supply the AMA percentage hearing impairment. A best and worst ear AMA were calculated and used to calculate an AMA hearing impairment percentage. Using the date of the most recent audiogram and the “engage date” to indicate date of employment (as used by the mine) working years were calculated. Unfortunately this information was not available for all participants and analyses were only done were this calculation was possible. Using the date of the most recent audiogram and the date of birth, an age at test was calculated. Different categories for ages as well as working years were calculated using these dates.

4.9.2. Data cleaning

Data were cleaned by identifying and correcting erroneous codes (Dane, 1990). When data were transferred from the Everest software programme to Microsoft Excel 2007/2010, several instances of incorrect numbering, unreliable data and more were evident, for instance, many participants and three or even more audiograms per year. These audiograms as well as audiograms with errors were deleted from the data set. The original amount of Microsoft Excel 2007 rows/ audiogram records was

22 3873. After data cleaning 171441 Microsoft Excel data rows (audiogram records) were available for use. (A total of 52 432 rows were deleted).

The following table summarises these errors and the cleaning of the data.

Table 4-8 Summary of data cleaning done, reasoning and amount of audiogram data disregarded (Data cleaning reduced dataset from 223 873 records to 171 441 records)

Disregarded audiogram records	Reason for deletion	Amount
All duplicates were removed (Same worker, same day, same time, same audiogram)	Redundant	3 855 records deleted
All rows where an audiogram error code was recorded in threshold value cells between 500-4000Hz were deleted.	Values in these frequencies are important for calculations of hearing impairment	640 records deleted
All rows where No Response (NR) values were recorded in more than 4 frequencies in one ear. Where a diagnostic test (5) for these workers was available, the results of the diagnostic test were kept in the file.	Values in these frequencies are important for calculations of hearing impairment. No hearing impairment calculations (Instruction 171) are possible without values at these frequencies. According to the Occupational Medical doctor mostly NR values are given when a worker did not participate or results were inconsistent.	150 records deleted
Where NR (no response) values were recorded for one or two frequencies (mostly high frequencies), and where results correlated with previous audiogram results (within 10dB's) maximum values (100dB) were given.	The mine audiometre has a maximum value of 99dB. If no value is given to these NRs, the calculations would be invalid. A 100dB value makes the researcher's change apparent and reflects the hearing loss without affecting the calculation significantly.	976 records deleted
No date of birth, thus no age groups		331 records deleted
All rows where one ear had normal threshold values and the other NR values	These results indicate a unilateral functional hearing loss (malingering). Interaural attenuation makes this scenario impossible	33 records deleted

Disregarded audiogram records	Reason for deletion	Amount
All audiograms marked as type2 (monitor) were changed to screen	This code was used very infrequently and no differences in pattern of use could be distinguished between the use of the screening code (1) and code (2).	
All rows where 2 or more tests were done on the same day were reduced in the following manner: • If a baseline (3) and baseline check (7) were similar the check (7) was deleted; • If two audiograms done on the same day were similar but a third not, the third was deleted; • If a screen(1) was followed by a diagnostic test(5) on the same day, the screen was deleted; • A test done for compensation (code 4) was kept if more than one test for the day was available; • If a diagnostic (5) or baseline audiogram (3) or screen (1) was repeated, the second test was kept (if it was similar to the first (+/- 5dB); • Tests done more frequently than once a year were not kept; • Exit tests (6) were done very often on the same day as a screening test (1). Only one test was kept and a code 6 was regarded as the same as a screening test (1).	Most baseline tests (3) followed on a baseline check (7). Baseline tests were done after the check and are more reliable. If more than one test of the same worker done on the same day were used, more weighting would be given to that audiogram. Diagnostic tests are more reliable than screening tests Test done for compensation is regarded as the final diagnosis	46 447 rows were deleted

4.9.3. Statistical analyses

After data-cleaning the data were analysed in collaboration with an experienced biostatistician from the Medical Research Council (Professor Piet Becker) according to a statistical analysis system (StataCoro. 2007. Stata Statistical Software: Release 10. College Station, TX: StataCorp LP). Both descriptive and inferential statistics were employed. Descriptive statistics served to organise and summarise this particular set of observations in a manner convenient for numerically evaluating the attributes of the available data (Maxwell & Satake, 2006). Tables and line graphs were primarily used to provide a visual and readily interpretable summary of the data. Measures of central tendency (means) and measures of variability (standard deviations, confidence intervals) were used. As threshold distributions of population-based samples (unlike distributions of multiple estimates for an individual) are usually positively skewed (ANSI, 1996), showing greater mean values compared to median values, the audiometric threshold distributions of the HFA346 and the LFA512 results (with the HFA346 indicative of noise-induced hearing loss (NIHL)) as well as per frequency analyses were analysed by their medians (50th percentile) and 95th percentiles. Medians for this study were calculated by the conventional method, where for example the the median of a group of 15 would be simply the 8th-ranked value. Another method used by some of the population standards (ISO 1990:1999), used for comparisons with this study's medians, calculated the median for grouped data, assuming that the cases in each 5-dB interval are evenly distributed (Dobie, 2006).

Inferential statistics allowed the researcher to generalise findings from the study sample to a similar group (population) from which the sample was drawn (Maxwell & Satake, 2006). To avoid any confounding influence of age in comparisons, 'age at test' was adjusted for during analyses using ANCOVA. This analysis of covariance (ANCOVA) is a procedure for comparing mean values of research variables while controlling for the influence of a continuous variable (covariate) such as age. A subset analysis was conducted on two homogenous noise-exposure groups, i) drillers (with known high levels of noise exposure) and the administrative personnel (with no known occupational noise exposure). Noise-concentration files received from the mine's occupational hygienist showed that drillers are exposed to drilling noise with an average of 140,85 dB (A), a minimum exposure level of 129,4 dB (A) and

Analysis of covariance (ANCOVA) and pairwise comparisons were used to establish whether statistically significant relationships existed between variables. To detect specific differences when groups were found to be significantly different ($p<0.05$) in the ANCOVA, pairwise comparisons between groups were done according to Fisher's Least Squares Differences Approach (F test). Given a null hypothesis and a significance level, the corresponding F test rejects the null hypotheses if the value of the F statistic is large (Le Prell, et al., 2007). The *p* value is understood as the probability that a null hypothesis were true. T-Tests, to determine significant differences between the mean scores of two groups, were also used to determine p-values. If the *p* value is smaller than a predetermined alpha level (0,05 for this study) it can be considered statistically significant, and the null hypothesis is rejected and the alternative hypothesis accepted (Brewer & Stockton, 2010). It is important to note that although some observed differences were statistically significant, the may not be clinically relevant. These statistical differences were mainly attributed to the very large sample size resulting in very small standard errors, where $t = \frac{x1 - x2}{\sqrt{\frac{SD1}{n1} + \frac{SD2}{n2}}}$. (Large t-values result in very small p-values).

4.10. Validity and reliability

Underpinning the research endeavours is the question of credibility. The researcher needs to ensure that the conclusions are reliable and valid. In general, the validity of a measurement instrument is the extent to which the instrument measures what it is supposed to measure (Leedy, 2001). By controlling the threats to validity the investigator can eliminate many variables that could influence the results of the study (DeForge, 2010). Threats are often referred to as alternative explanations.

Four main sources of threats have been identified: internal, statistical conclusion, construct and external (DeForge, 2010). The internal validity of the research project as a whole has to do with its accuracy, meaningfulness and credibility (Dane, 1990). Internal validity focuses on what occurred during the implementation of the study that could influence the relationship between the independent and dependent variables (DeForge, 2010). The audiometric data that were used for analysis were collected using standards that are accepted worldwide as valid and reliable measures of hearing (SANS10083:2004, 2004). The PLH that was used is calculated using methods that are enforced by the Mine and Health Safety Act of South Africa (RSA, Department of Labour, 2001). Threats to the internal validity include the lack of information on recreational noise exposure of the participants. Recreational activities with excessively loud sound levels are an increasingly important factor to consider when investigating total noise exposure in workers (Neitzel, Seixas, Goldman, & Daniell, 2004). At football games for instance (a very popular recreational activity in South Africa) it has been shown that a real risk of noise-induced hearing loss is present because of the high levels of noise emitted by the vuvuzela (a horn-like instrument used during these games) (Swanepoel & Hall, 2010). Other threats include the lack of a working history for most workers and the use of screening audiograms where diagnostic data were not available. To control for these threats diagnostic hearing tests were uses whenever possible and audiogram data, obtained from diagnostic tests, were used in all cases where hearing loss deteriorated more than 10% between the baseline and subsequent hearing tests.

Validity also relies on the validity of the statistical conclusion. This involves the inferences about the correlation or co-variation between independent and dependent variables (DeForge, 2010). The statistician involved in this project has been involved in numerous human research studies at the Medical Research Council, acts as the principal statistician at the MRC, and provided guidance and mentoring to ensure that statistical analysis was conducted accurately.

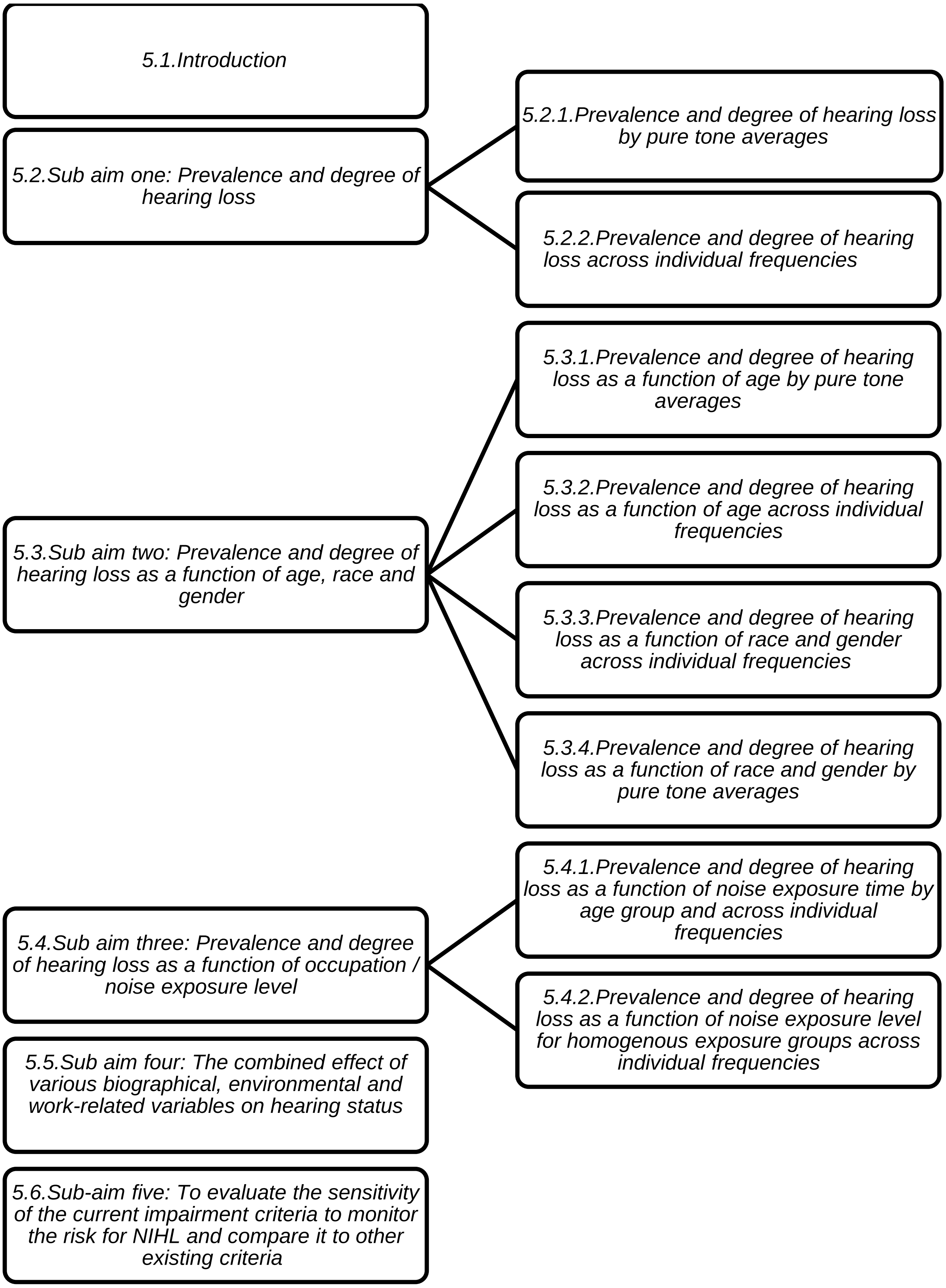
The study’s external validity is dependent on the representativeness of the sample (Leedy, 2001). Where the population is viewed as all gold miners in South Africa the large group of participants that participated in this study increased the representativeness of the sample. Generally it can be said that the larger the sample used in an investigation, the more accurate the estimate of the standard error was (Maxwell & Satake, 2006). Based on 2007 statistics (AngloGold Ashanti, 2007; Mwape et al., 2007) a sample of 30 650 gold miners represented 19,15% of the total gold miners’ population (159 984). According to Gay (1995, as cited in Maxwell & Satake, 2006) 10-20 % of the population should be sampled for descriptive purposes and at least 30 participants are required for correlational studies. It is clear that the sample represents a sufficiently large proportion of the population of South African gold miners. The external validity is limited to the gold mining industry as other characteristics such as migrant living conditions and exposure to external agents, such as silica dust, that is used in the mining process for example, are specific to this population. As the entire population of the seven specific gold mines partaking in this investigation is included conclusions reached reliably represent these specific mines.

4.11. Chapter summary

In this chapter the research design and methodology were explained. The research question, aims and hypotheses were offered and explained. The methodology followed for the empirical part of the study was also presented with specific account of the data organisation (collection, cleaning and organisation), participant criteria, descriptive statistics, as well as the inferential statistics applied to investigate and describe the research constructs.

Chapter 5 subsequently presents all the findings obtained by applying the research methodology as explained in Chapter 4.

5. Results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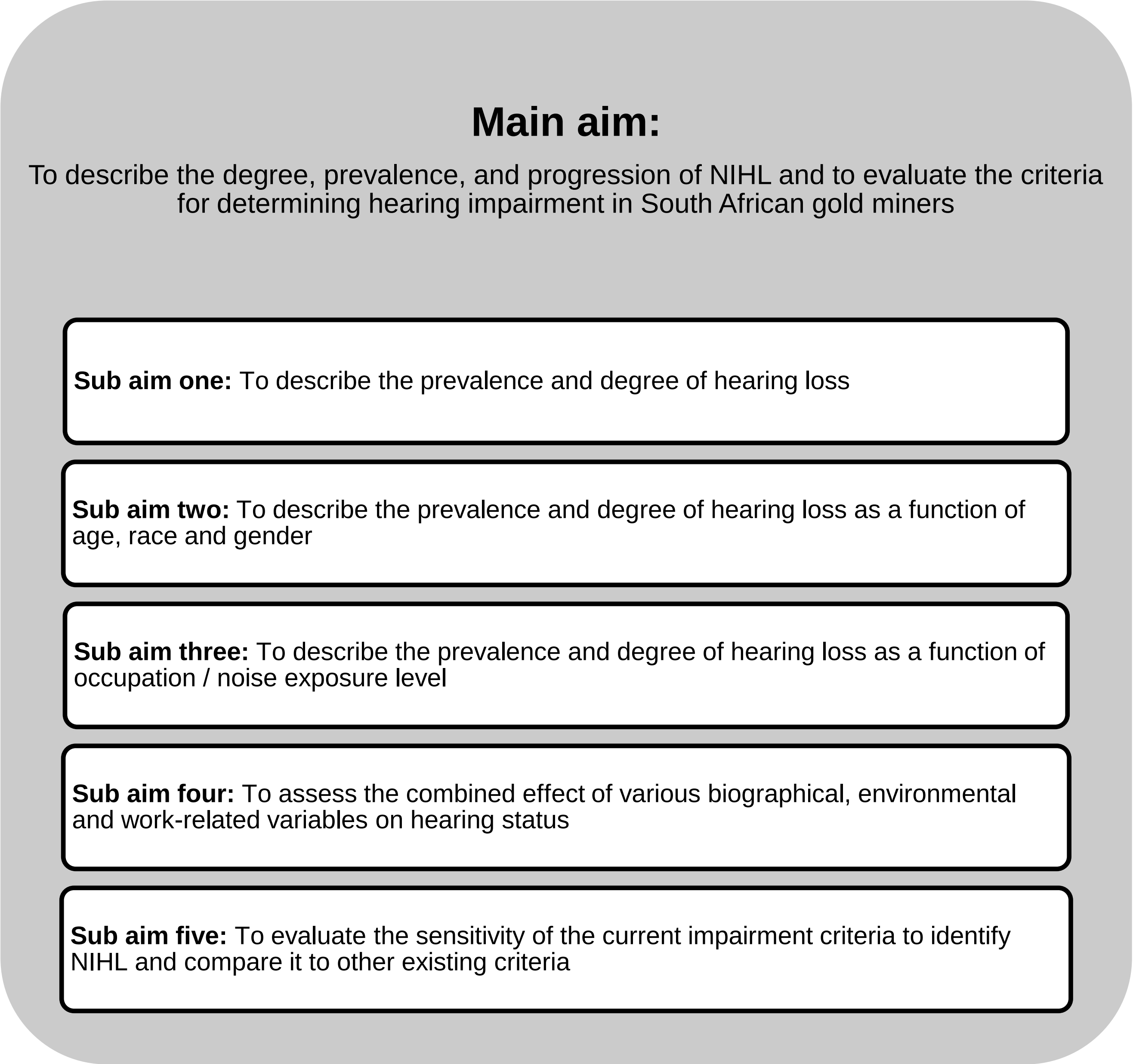
5.1. Introduction

In this chapter the results will be discussed according to the sub aims as set out in chapters one and three. The main aim of this study was to describe the degree, prevalence, and progression of NIHL and to evaluate the criteria for determining hearing impairment in South African gold miners. To aid navigation through the results' section the following graph presents the sub aims specified to attain the main aim of the research.



Main aim:

To describe the degree, prevalence, and progression of NIHL and to evaluate the criteria for determining hearing impairment in South African gold miners

Sub aim one: To describe the prevalence and degree of hearing loss

Sub aim two: To describe the prevalence and degree of hearing loss as a function of age, race and gender

Sub aim three: To describe the prevalence and degree of hearing loss as a function of occupation / noise exposure level

Sub aim four: To assess the combined effect of various biographical, environmental and work-related variables on hearing status

Sub aim five: To evaluate the sensitivity of the current impairment criteria to identify NIHL and compare it to other existing criteria

Figure 5-1 Sub aims of this study constituting the main aim

For sub aim one, two, and three, describing prevalence and degree of NIHL in the cohort of gold miners (and within different groups, age, race, gender and noise), hearing test results were compared to accepted criteria for normal hearing as will be set out in the following paragraph. For sub aim four, to estimate the combined effect of NIHL and various biographical and environmental variables in this cohort, hearing threshold distributions will be compared to demographically matched control groups to evaluate if hearing thresholds are typical for a matched demographic group. A synthesis of reported effects culminated in the development of the ISO 1990:1999 and the nearly identical ANSI S3.44 (1996) guidelines. Hearing thresholds of the cohort (with daily noise exposure above 85 dB A) will be compared to these guidelines as well as to a control group with no known occupational noise exposure from the same cohort.

For sub aims one to three hearing status was assessed by analyses of hearing thresholds per frequency (section 5.2.2). Thresholds were also classified in categories based on degree of impairment (section 5.2.1) as proposed by Yantis (1994) and used by Picard et al. (2008) and Girard et al. (2009). NIHL is defined as a bilateral high frequency hearing loss (Picard, et al., 2008). Based on the data from this large scale study (N=53000) Picard (2012) suggests that within the context of NIHL, Yantis' low fence at 16 dB HL appears to be a sensible cut-off point to decide on the presence of some minimal degree of hearing loss. Furthermore, the distribution of their data showed only a few outliers beyond the 60 dB HL mark. As a whole, their data indicate that the Yantis classification may be a finer grain scale to represent NIHL (Picard, 2012).

The bilateral high frequency hearing loss is operationally defined as the bilateral average value of 3, 4, and 6 kHz (HFA346) and was used in calculations. In order to aid comparison average hearing thresholds at 0,5, 1 and 2 kHz, (low frequency average (LFA312)) were also calculated and used during analyses elsewhere in this section.

Hearing sensitivity categories ranged from normal (0-15 dB HL) to the largest permanent loss, labelled “severe” (>50 dB HL) according to the criteria set out by Yantis (1994). Intermediate degrees are specified in table 5.1.

Table 5-1 Hearing threshold categories based on the degree of impairment proposed by Yantis (1994) and used by Picard (2008) and Girard (2009)

Category of hearing sensitivity	Defined: ○ Per frequency/ ○ Per hearing threshold average for high frequencies (3, 4, 6 kHz) (HFA346)/ ○ Per hearing threshold average for low frequencies (0.5, 1 and 2 kHz)(LFA312)
Normal hearing	0-15 dB
Just noticeable hearing loss	16 to 30 dB
Mild hearing loss	31 to 40 dB
Moderate hearing loss	41 to 50 dB
Severe hearing loss	≥51 dB

5.2. Sub aim 1: Prevalence and degree of hearing loss

5.2.1. Prevalence and degree of hearing loss by pure tone averages

In order to describe the prevalence of hearing loss in the group of gold miners it is necessary to firstly determine whether a hearing loss was present and to see if this hearing loss can be ascribed to noise. Participants with no known exposure to occupational noise were grouped into the No Noise Group which included workers such as administrative workers and workers in the accounts' department. Participants with occupational noise exposure above 85 dB A over an 8-hour working day (classified according to the South African regulations on the daily permissible dose of noise exposure (SANS10083:2007, 2007)) and who worked underground were grouped into Noise Group 1 and included occupations such as drillers and boilermakers. Participants with known occupational noise exposure above 85 dB A over the 8-hour working day and who worked above ground (such as "boilermaker, surface") were grouped into Noise Group 2. Table 5.2 summarises the proportion of workers in the three noise-exposure groups, by category of hearing sensitivity (bilateral high frequency average (HFA346) (3, 4, 6 kHz) as well as the bilateral low frequency average (LFA312) (0.5, 1, 2 kHz)) (Yantis, 1994).

In order to aid comparison with studies making use of the ISO 1990:1999 age categories table 5.3 summarises the distribution of workers according to hearing sensitivity (bilateral HFA346), noise exposure levels and ISO 1990:1999 age categories.

Table 5-2 Distribution of workers according to hearing sensitivity (bilateral HFA346 and LFA312) and noise-exposure levels ($\mathbf{N_{0-15} + N_{15-30} + N_{31-40} + N_{41-50} + N_{51+} = N_1 / N_3 / N_2}$)

Category of hearing sensitivity (dB)*	Participants grouped into different Noise Groups					
Bilateral HFA346 (3, 4, 6 kHz)	Noise Group 1 ≥85 dB A Underground		Noise Group 2 ≥85 dB A Surface		No Noise Group <85 dB A	
	N_1= 33749	100%	N_2= 7456	100%	N_3= 6162	100%
Normal hearing 0-15 dB	N_{0-15} 15388	45,5%	N_{0-15} 3668	49,1%	N_{0-15} 3297	53,5%
Just noticeable HL 16 to 30 dB	N_{15-30} 11389	33,7%	N_{15-30} 2329	31,2%	N_{15-30} 1871	30,3%
Mild HL 31 to 40 dB	N_{31-40} 3153	9,3%	N_{31-40} 660	8,8%	N_{31-40} 498	8%
Moderate HL 41 to 50 dB	N_{41-50} 1817	5,3%	N_{41-50} 396	5,3%	N_{41-50} 249	4%
Severe HL 51+dB	N_{51+} 2002	5,9%	N_{51+} 403	5,4%	N_{51+} 247	4%
Bilateral LFA512 (0,5, 1, 2 kHz)	Noise Group 1 ≥85 dB A Underground		Noise Group 2 ≥85 dB A Surface		No Noise Group <85 dB A	
	N_1= 33749	100%	N_2= 7456	100%	N_3= 6162	100%
Normal hearing 0-15 dB	N_{0-15} 25934	76,8%	N_{0-15} 5807	77%	N_{0-15} 4992	81%
Just noticeable HL 16 to 30 dB	N_{15-30} 5687	16,9%	N_{15-30} 1228	16%	N_{15-30} 903	14,7%
Mild HL 31 to 40 dB	N_{31-40} 1199	3,6%	N_{31-40} 236	3%	N_{31-40} 172	2,8%
Moderate HL 41 to 50 dB	N_{41-50} 463	1,4%	N_{41-50} 107	1%	N_{41-50} 59	1%
Severe HL 51+dB	N_{51+} 466	1,4%	N_{51+} 78	1%	N_{51+} 36	0,6%

*hearing loss (HL)

Table 5-3 Distribution of workers according to hearing sensitivity (bilateral HFA346), noise-exposure levels and ISO 1990:1999 age categories

Category of hearing sensitivity (dB)* **Age group (ISO 1990:1999)**	**Participants grouped into different Noise Groups**			
Bilateral HFA346 (3, 4, 6 kHz)	Noise Group 1 ≥85 dB A Underground Total=31105		No Noise Group <85 dB A Total=5668	
Age 25-35 years	N=8934	100%	2096	100%
Normal hearing 0-15 dB	6557	73,39	1553	74,09
Just noticeable HL 16 to 30 dB	1978	22,14	452	21,56
Mild HL 31 to 40 dB	226	2,52	59	2,81
Moderate HL 41 to 50 dB	112	1,25	12	0,57
Severe HL 51+dB	61	0,68	20	0,95
Age 36-45 years	12303	100%	2158	100%
Normal hearing 0-15 dB	4998	40,62	1074	49,76
Just noticeable HL 16 to 30 dB	5100	41,45	775	35,91
Mild HL 31 to 40 dB	1189	9,66	175	8,01
Moderate HL 41 to 50 dB	516	4,19	72	3,33
Severe HL 51+dB	500	4,06	62	2,87
Age 46-54 years	8087	100%	1196	100%
Normal hearing 0-15 dB	1415	17,49	228	19,06
Just noticeable HL 16 to 30 dB	3493	43,19	523	43,72
Mild HL 31 to 40 dB	1378	17,03	203	16,97
Moderate HL 41 to 50 dB	884	10,93	134	11,2
Severe HL 51+dB	917	11,33	108	9,03
Age 56-65 years	1781	100%	218	100%
Normal hearing 0-15 dB	131	7,35	12	5,5
Just noticeable HL 16 to 30 dB	533	29,92	70	32,11
Mild HL 31 to 40 dB	320	17,96	53	24,31
Moderate HL 41 to 50 dB	295	16,56	27	12,38
Severe HL 51+dB	502	28,18	56	25,68

*hearing loss (HL)

According to Table 5.2 the majority of participants were exposed to noise levels above 85 dB A, and were exposed to these noise level underground (Noise Group 1, N=33749), followed by workers exposed to high noise levels above ground (Noise Group 2, N=7456) and those who were not exposed to known occupational noise (No Noise Group, n=6162). Based on the bilateral LFA512 results in table 5.2 the proportions of workers displaying a hearing loss, not normal hearing, were 19% of the No Noise Group, 23% of Noise Group 2 and 23,2% of Noise Group 1. Even though the majority of participants in all the Noise Groups were still grouped into the normal hearing category based on the HFA346 results, the group proportions for workers with hearing loss were larger compared to the proportions when the results were used (46,5% of the No Noise Group, 50,9% of Noise Group 2, and 54,5% of Noise Group 1).

In all noise groups the proportion of participants in the “Just noticeable (HL 16 to 30 dB)” hearing sensitivity category was considerably higher based on the HFA346 than on the LFA512. These percentages range from 30,3% to 33,7% for the HFA346 versus 14,7% to 16,9% for the LFA512 thresholds. Based on the LFA512 as well as the HFA346 results, the proportion of workers in the normal hearing group was smallest for Noise Group 1. The No Noise Group had the highest proportion of participants in the normal hearing category (HFA346 and LFA512 results) compared to the other noise groups. Of all the Noise Groups only a small proportion revealed the HFA346 as well as the LFA512 results in the severe hearing sensitivity category. For the HFA346 results though, percentages varied from 4% to 5% versus 0,6% to 1,4% for the LFA512. Noise Group 1 had the highest proportion of participants (6%) in the severe hearing sensitivity category.

Table 5.3 shows that the largest difference in the proportion of participants with high frequency hearing loss was observed in the age group 36-45 years. In this age category 14% of the participants of the No Noise Group had high frequency hearing loss worse than 30 dB HL compared to the 18% for Noise Group 1.

In order to compare the proportions of the different Noise Groups the confidence interval for the proportion differences in each hearing sensitivity category was calculated and is shown in table 5.4. The proportions from two noise groups differ significantly when zero is excluded from the 95% CI for the difference between the proportions. The 95% CI for the differences between two proportions were determined using the normal approximation for the binomial distribution.

Table 5-4 The 95% confidence intervals (CI) for the difference of the population proportions between Noise Group 1 and No Noise Group (Table 5.4 a) and between Noise Group 2 and No Noise Group (Table 5.4 b) according to hearing sensitivity, for high frequency averages (HFA346) and low frequency averages (LFA512)

Table 5.4 a **Confidence intervals for the proportion differences between Noise Group 1 and No Noise Group ***		
High Frequency Average (3, 4, 6 kHz)		
Category of hearing sensitivity	95% CI for the difference between group proportions**	Noise group with higher proportion per category**
Normal hearing 0-15 dB	(-0,91 ; -0,64)	No Noise Group
Just noticeable HL* 16 to 30 dB	(0,02 ; 0,045)	Noise Group 1
Mild HL 31 to 40 dB	(0,004 ; 0,019)	Noise Group 1
Moderate HL 41 to 50 dB	(0,007 ; 0,018)	Noise Group 1
Severe HL 51+dB	(0,013 ; 0,024)	Noise Group 1
Low Frequency Average (0.5, 1, 2 kHz)		
Category of hearing sensitivity	95% CI for the difference between group proportions **	Noise group with higher proportion per category**
Normal hearing 0-15 dB	(-0,52 ; -0,305)	No Noise Group
Just noticeable HL 16 to 30 dB	(0,117 ; 0,031)	Noise Group 1
Mild HL 31 to 40 dB	(0,003 ; 0,012)	Noise Group 1
Moderate HL 41 to 50 dB	(0,001 ; 0,006)	Noise Group 1
Severe HL 51+dB	(0,005 ; 0,01)	Noise Group 1

*Hearing loss (HL), Noise Group 1: ≥85 dB A Underground Noise; Noise Group 2: ≥85 dB A Surface Noise; No Noise Group: no known occupational noise

** Statistical significance between proportions is attained at the 0.05 level of significance when zero is excluded from the 95% confidence interval

Table 5.4 continues on the next page

Table 5.4 b (continue)

Confidence intervals for the proportions differences between Noise Group 2 and No Noise Group *

High Frequency Average (3, 4, 6 kHz)

Category of hearing sensitivity	95% CI for the difference between group proportions **	Noise group with higher proportion per category**
Normal hearing 0-15 dB	(-0,059 ; -0,025)	No Noise Group
Just noticeable HL 16 to 30 dB	(-0,007 ; 0,024)	No significant difference
Mild HL 31 to 40 dB	(-0,002 ; 0,016)	No significant difference
Moderate HL 41 to 50 dB	(0,005 ; 0,019)	Noise Group 2
Severe HL 51+dB	(0,007 ; 0,021)	Noise Group 2

Low Frequency Average (0,5, 1, 2 kHz)

Category of hearing sensitivity	95% CI for the difference between group proportions **	Noise group with higher proportion per category**
Normal hearing 0-15 dB	(-0,017 ; -0,045)	No Noise Group
Just noticeable HL 16 to 30 dB	(0,005 ; 0,298)	Noise Group 2
Mild HL 31 to 40 dB	(-0,017 ; 0,009)	No significant difference
Moderate HL 41 to 50 dB	(0,001 ; 0,008)	Noise Group 2
Severe HL 51+dB	(0,004 ; 0,007)	Noise Group 2

*Hearing loss (HL), Noise Group 1: ≥85 dB A Underground Noise; Noise Group 2: ≥85 dB A Surface Noise; No Noise Group: no known occupational noise

** Statistical significance between proportions is attained at the 0,05 level of significance when zero is excluded from the 95% confidence interval

Table 5.4 summarises the CIs for the differences in proportions between Noise Group 1 (≥85 dB A Underground Noise) and the No Noise Group (in table 5.4 a) and Noise Group 2 and the No Noise Group (in table 5.4 b) for the different hearing sensitivity groups either the HFA346 or the LFA512 results. In table 5.4 a results for the HFA346 indicated that Noise Group 1 had a significantly higher proportion of participants in all the hearing-loss groups, slight, mild, moderate, and severe than the No Noise group. The proportion of participants with normal hearing was significantly more for the No Noise Group than for Noise Group 1. This was also true for the LFA512 results, where there was a significantly higher proportion of participants in Noise Group 1 in all hearing loss categories (slight, mild, moderate, and severe) than the proportion of participants in these groups for the No Noise Group; and a significantly higher proportion of participants in the normal hearing category for the No Noise Group than for Noise Group 1.

Table 5.4 b shows the differences in proportion sizes between the No Noise Group and Noise Group 2 (≥85 dB A Surface Noise). For HFA346 and LFA512 averages the No Noise Group had a significantly larger proportion of participants in the normal hearing group than those of Noise Group 2. Noise group 2 had a significantly larger proportion of participants than the No Noise Group in the following instances: HFA346 results for the moderate and severe hearing loss groups, and LFA512 results for the just noticeable, moderate, and severe hearing-loss groups.

The audiometric threshold distributions of the HFA346 and the LFA512 results (with the HFA346 indicative of noise-induced hearing loss (NIHL) were analysed by their medians (50th percentile) and 95th percentiles. The 5th percentile values are not shown as all these values were 0dB HL. Table 5.4 showed a small difference between Noise Group 1 and 2 proportions. As Noise Group 2 participants had greater variability in terms of noise-exposure limits and daily-noise dosage than Noise Group 1 participants (Eloff, 2009) statistical analyses were limited to Noise Group 1 and the No Noise Group. These values derived from thresholds from participants in Noise Group 1 and the No Noise Group are demonstrated in figures 5.2, 5.3 and 5.4.

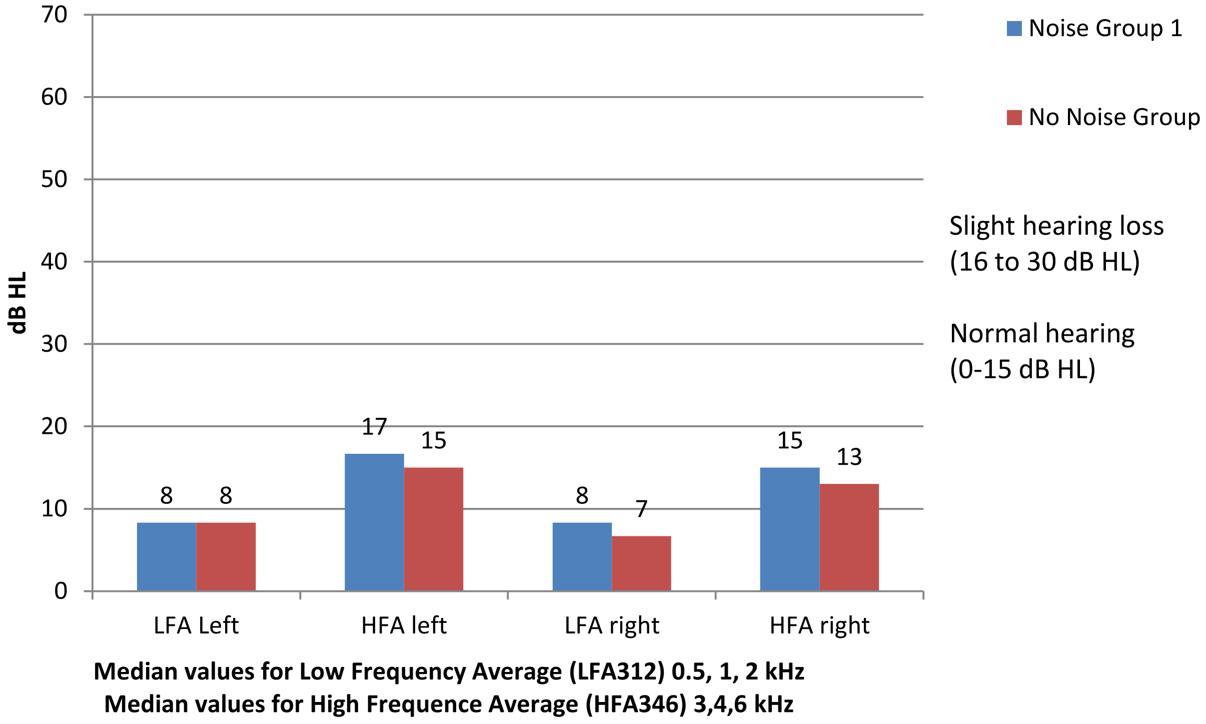


Figure 5-2 Median values for the HFA346 and the LFA512 for Noise Group 1 and No Noise Group (Noise Group 1: Underground occupational noise ≥85 dB A TWA (n= 33961); No Noise Group: No known occupational noise (n=6194))

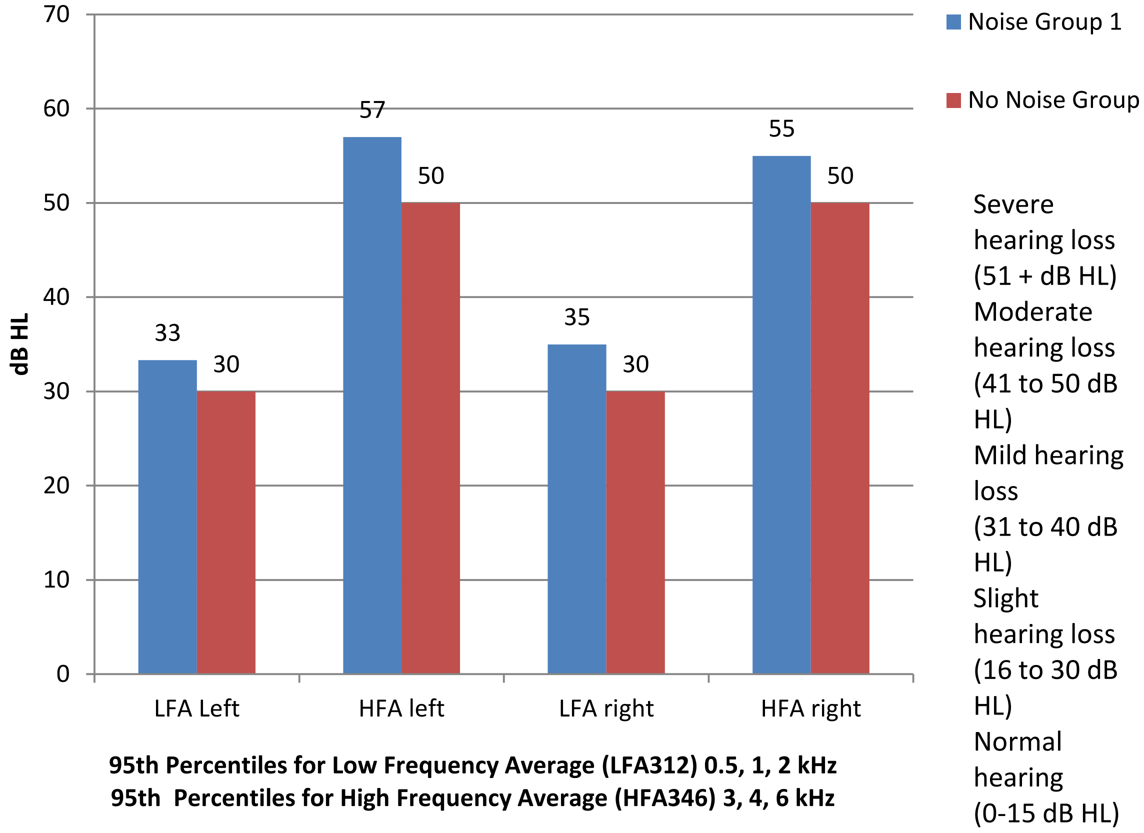


Figure 5-3 95th Percentile values for the HFA346 and the LFA512 for Noise Group 1 and No Noise Group (Noise Group 1: Underground occupational noise ≥85 dB A TWA n= 33961; No Noise Group: No known occupational noise n=6194)

All the results (shown in figures 5.2 and 5.3) show larger values, medians and 95th percentile values, for Noise Group 1 than for the No Noise Group. Both graphs show elevated thresholds where high frequencies (3, 4 and 6 kHz) were used for analyses (HFA346) compared to the low frequency averages (LFA512; 0,5, 1 and 2 kHz). All the values, median and 95th percentile, for left ear thresholds are slightly elevated compared to those of the right ears. The largest difference (with clinical significance) was seen between the 95th percentile values derived from the HFA346 for the left ears for Noise Group 1 and the No Noise Group (Noise Group 1 had a HFA346 of 57 dB HL and the No Noise Group had a HFA346 of 50 dB HL).

In an ANCOVA Noise Group 1 and the No Noise group differed significantly with respect to mean LFA512 (p=0,0001; 11,65dB versus 11,03dB) and mean HFA346 (p=0,0072; 11,45dB versus 10,81dB) after adjusting for age (Noise Group 1 more elevated than No Noise Group). However, although statistically significant this difference is clinically insignificant.

Figure 5.2 further reveals that the median HFA346 values for Noise Group 1 fell within the “slight hearing loss” category (16 to 30 dB HL). Median values for the No Noise Group (HFA346, left and right ears) revealed threshold values within the “normal hearing” category (0-15 dB HL). The 95th percentile values for participants in Noise Group 1 (HFA346 thresholds for left and right ears) fell within the “severe hearing loss” category (51+ dB HL) compared to these results for the No Noise Group participants that fell within the “moderate hearing loss” category (41 to 50 dB HL).

Bilateral LFA512 and HFA346 values (median and 95th percentile) for Noise Group 1 and the No Noise Group are shown in figure 5.4 categorised according to the hearing sensitivity groups.

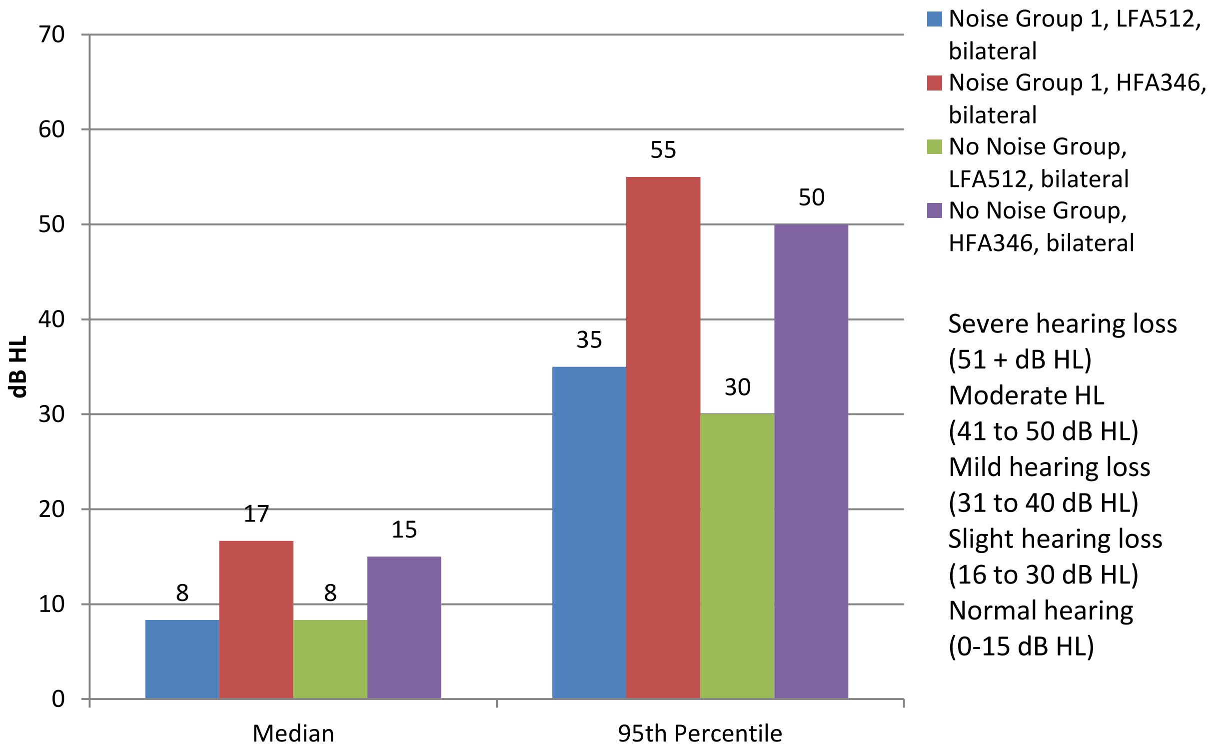


Figure 5-4 Median and 95th Percentile values for the pure tone average (PTA512) and high frequency average (HFA346) of participants in Noise Group 1 and No Noise Group (Noise Group 1: Underground occupational noise ≥85 dB A TWA , n= 33961; No Noise Group: Occupational noise <85 dB A, n=6194)

Results shown in figure 5.4 reveal that the HFA346 for thresholds are more elevated than the LFA512 for the hearing thresholds in all instances. Results revealed that median values for the two noise groups are at least 9 dB better for the LFA512 than for the HFA346 values. 95th percentile values for the LFA512 and the HFA346 results were 20dB more elevated for the HFA346 values for both noise groups. As in figure 5.2 and 5.3 the results for Noise Group 1 showed more elevated dB values, medians and 95th percentile, for all calculations, apart from the median values for the LFA512, for Noise Group 1 than for Group 3. The median values for the LFA512 for Noise Group 1 and the No Noise Group, and the median for the No Noise Group the HFA346 fell within normal limits. All other values revealed a degree of hearing loss.

5.2.2. Prevalence and degree of hearing loss across individual frequencies

In the previous section (section 5.2.1) it has been shown through analysis of the results that a larger proportion of the noise-exposed groups had elevated hearing thresholds for low frequency and high frequency averages. In this section the hearing levels will be explored further by describing thresholds for the noise-exposed and control groups across individual frequencies. As threshold distributions of population-based samples (unlike distributions of multiple estimates for an individual) are usually positively skewed (ANSI, 1996), showing greater mean values compared to median values, the audiometric threshold distributions were analysed by their medians (50th percentile) and 95th percentiles (all the 5th percentiles were 0 dB HL).

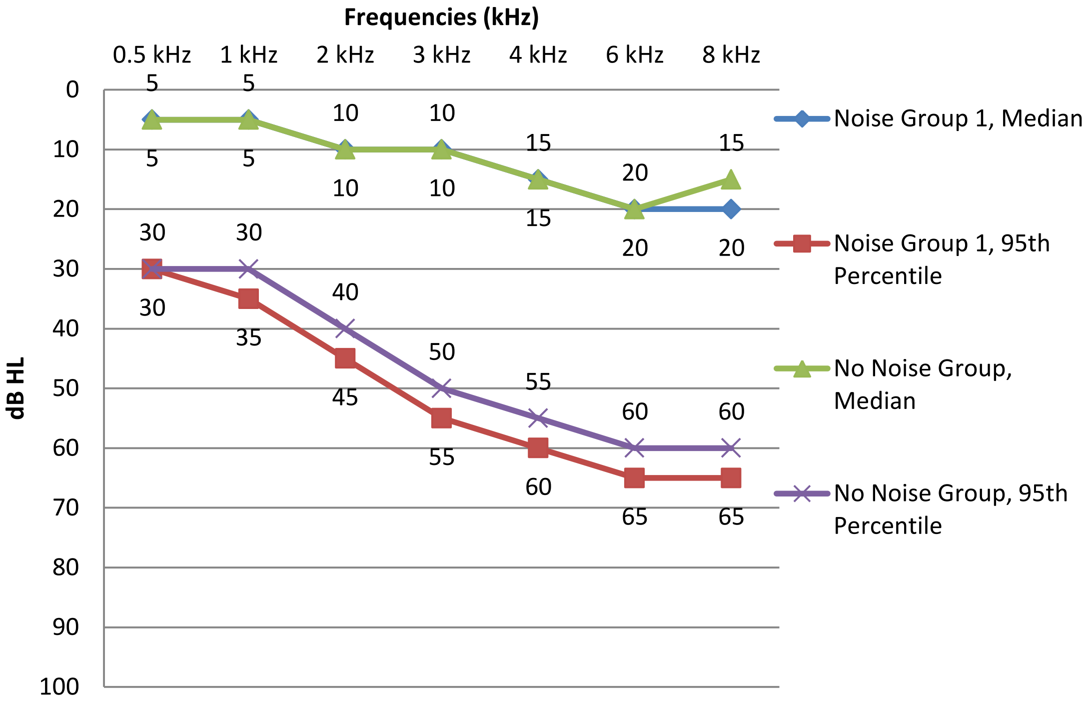


Figure 5-5 Left ear, medians and 95th percentile threshold values (dB HL) per frequency (Noise Group 1: Underground occupational noise ≥85 dB A (TWA), n= 33961; No Noise Group: No known occupational noise, n=6194)

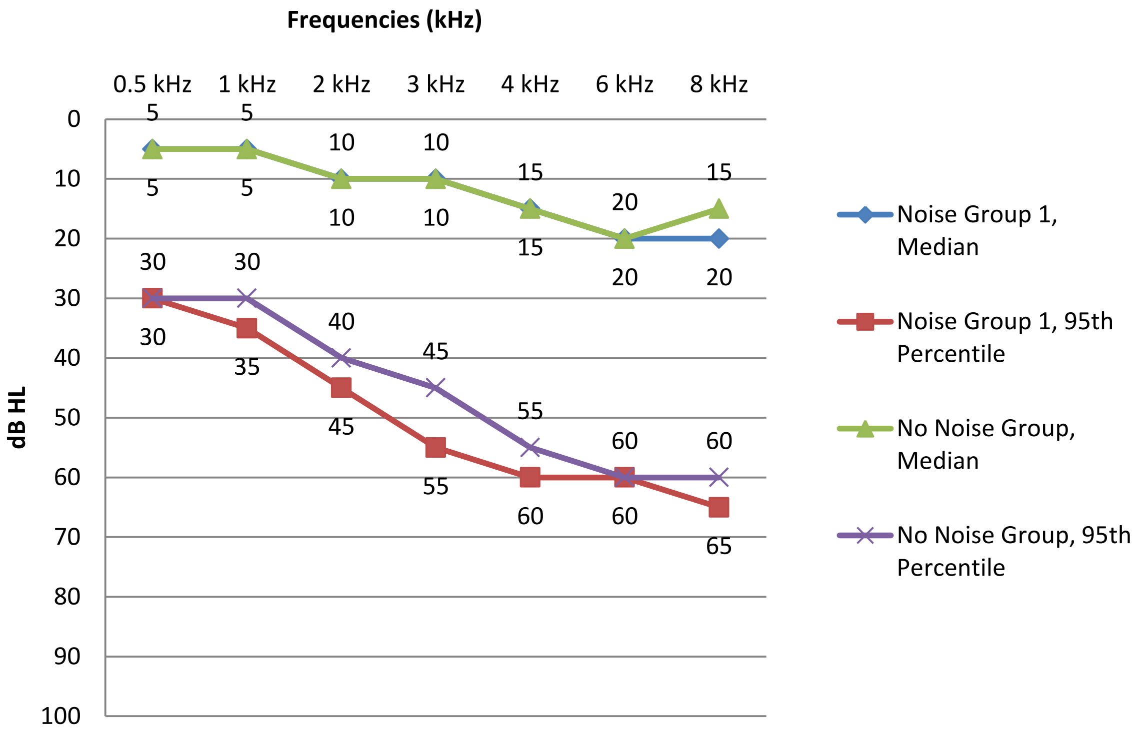


Figure 5-6 Right ear, medians and 95 percentile threshold values (dB HL) per frequency. Noise Group 1: Underground occupational noise ≥85 dB A TWA (n= 33961) No Noise Group: No known occupational noise (n=6194)

From figures 5.5 and 5.6 data for the left and right ears are identical except for the 95th percentile value for the No Noise Group that is 5 dB better for the right ear than for the left ear (45 dB HL). For Noise Group 1 and the No Noise Group the median values are identical for both ears for all frequencies except 8 kHz, where the No Noise Group shows 5 dB better median thresholds than the values for Noise Group 1. Through comparison between the threshold values for the two groups in the 95th percentile, it is demonstrated that the non-exposed group (No Noise Group) showed at least 5 dB better values over the whole frequency range (figure 5.5). Based on the notch criteria of Coles and colleagues (Coles, Lutman, & Buffin, 2000), defined as a high-frequency notch where the hearing threshold at 3, 4, and/or 6 kHz is at least 10 dB greater than at 1or 2 kHz and at least 10 dB greater than at 6 or 8 kHz, the greatest notch was observed in both groups at 6 kHz (15 dB notch).

5.3. Sub aim 2: Prevalence and degree of hearing loss as a function of age, race and gender

5.3.1. Prevalence and degree of hearing loss as a function of age by pure tone averages

To describe the prevalence of hearing loss in the group of gold miners the participants were divided into two different noise groups, namely the No Noise Group (no known occupational noise exposure) and Noise Group 1 (underground occupational noise exposure of ≥ 85 dB A). These participants were then further divided into different age groups. For the purposes of comparison these age groups were categorised as follows: 16 to 30 years, 31 to 40 years, 41 to 50 years, 51 to 60 years, and 61 to 65 years. Within these age categories the participants were divided based on the HFA346 and the LFA512 of their hearing thresholds into the different hearing sensitivity categories (Yantis, 1994) as described in section 5.2. The following tables show the numbers of participants in each of the age categories for Noise Group 1 and the No Noise Group.

Table 5-5 Breakdown of numbers (n) of participants (with percentage of sample indicated) categorised in the different Noise Groups and different age categories used for calculations of proportion of the different hearing sensitivity categories (shown in figures 5.7 and 5.8)

	16 to 30 Years	**31 to 40 Years**	**41 to 50 Years**	**51 to 60 Years**	**61 to 65 Years**	**Total n**
Noise Group 1	7568 22.3 %	11190 32.9%	11058 32.6%	3683 10.9%	250 0.8%	33961 100%
No Noise Group	1623 26.4%	2327 37.8%	1696 27.4%	492 7,9%	24 0.4%	6194 100%

From this table it is clear that sample sizes are large (with exception of the age group 61to 65 years). In figures 5.7 and 5.8 the percentage of participants in these different categories are shown as a proportion of the hearing sensitivity category. These calculations are based on the LFA512 thresholds and the HFA346 thresholds.

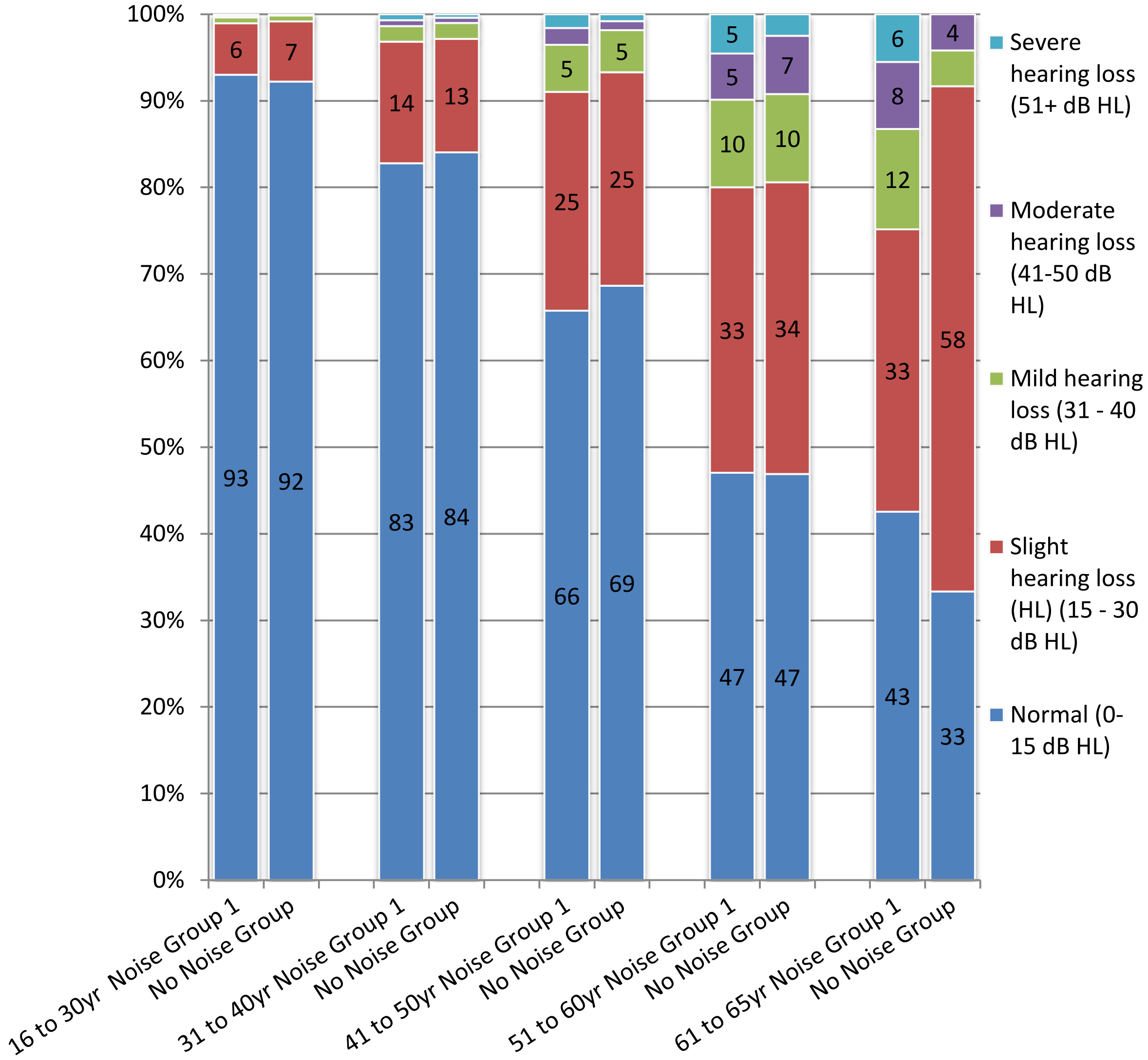


Figure 5-7 Percentage of participants in Noise Group 1 and the No Noise Group per age group across the hearing-sensitivity category for the Low Frequency Averages (LFA512)

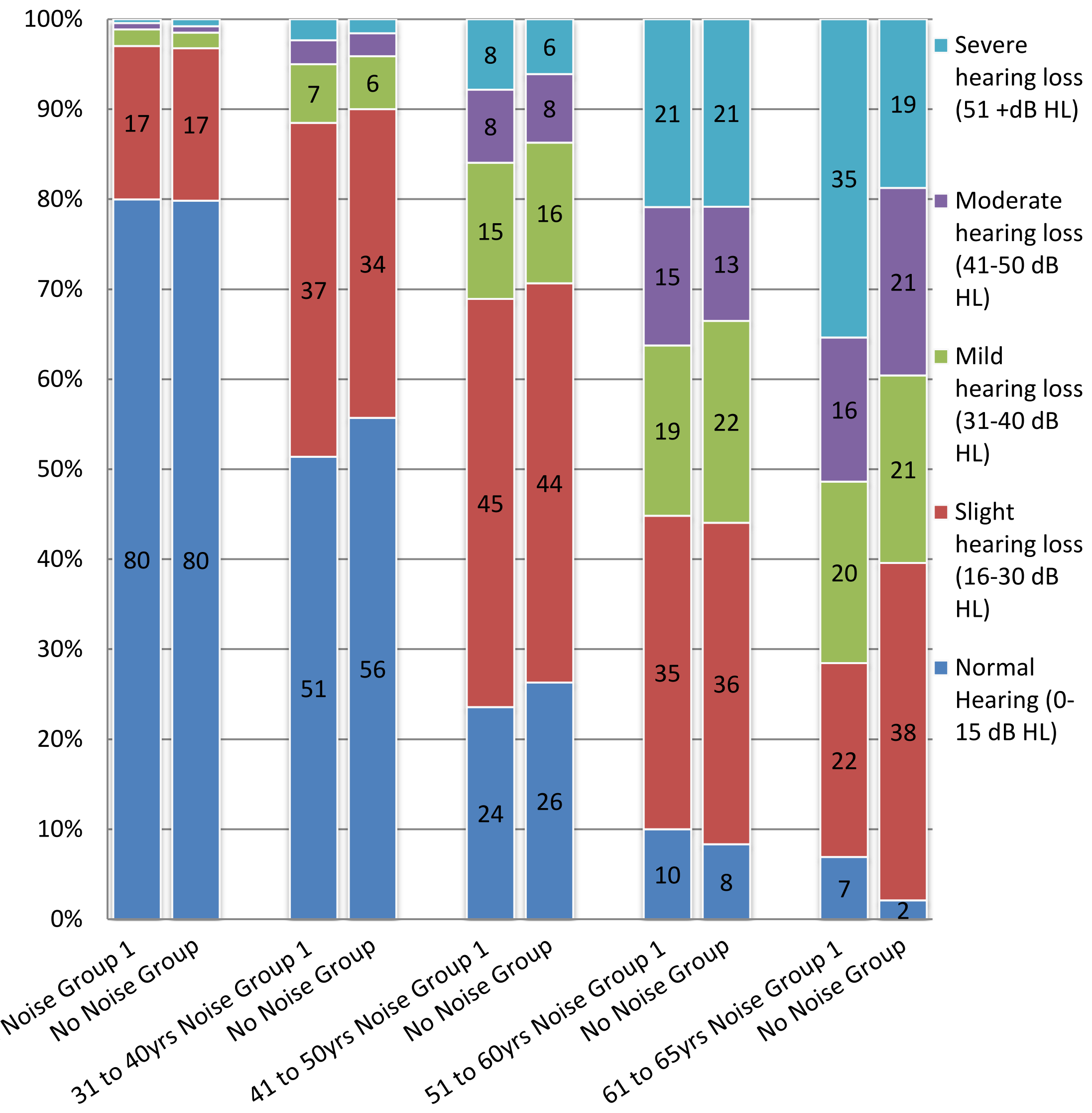


Figure 5-8 Percentage of participants in Noise Group 1 and the No Noise Group per age group per hearing sensitivity category for the High Frequency Averages (HFA512)

From figure 5.7 and 5.8 it is clear that the LFA512 results (figure 5.7) indicated a higher proportion of participants in all age groups in the normal hearing category compared to the proportion of participants in the normal category for the HFA346 results (figure 5.8). Figure 5.8, proportions based on the LFA512 results, show only a small proportion of participants in the mild to severe hearing sensitivity categories and only in the age groups 51 to 60 years and 61 to65 years. The largest differences between proportions of Noise Group 1 and the No Noise Group (in the different hearing sensitivity categories) were observed when the HFA346 of hearing thresholds were used.

Results shown in figure 5.8 reveal that the largest proportion of participants in the age group 16 to 30 years had HFA346 values within the normal hearing category (80% for Noise Group 1 and the No Noise Group). Virtually none of the participants in this age group had the HFA346 results within the mild-severe hearing-sensitivity category. Results for this age group are similar for Noise Group 1 and the No Noise Group. In the age group 31 to 40 years (HFA346 results) the largest proportion for both Noise Groups fell within the normal hearing group (51% Noise Group 1 and 56% No Noise Group) followed by the slight hearing-loss category. For both Noise Groups a small proportion of the participants between 31 and 40 years revealed hearing loss in the mild to severe hearing-loss categories (11% Noise Group 1 and 10% No Noise Group). For participants between 41 and 50 years (both Noise Groups) the largest proportion had the HFA346 thresholds between 16 to 30 dB HL (slight hearing-loss category). The majority of participants in the 51 to 60 years age group (for both Noise Groups) fell within the mild-severe hearing-loss categories (a slightly higher proportion for Noise Group 1 than the No Noise Group, 55% versus 56%). The largest difference between the proportions sizes of the different Noise Groups was observed for the severe hearing-loss category in the 61 to 65 years age group. 35% of participants in this age group had the HFA346 thresholds in the severe hearing-loss group compared to the 19% of the same age in the No Noise Group.

5.3.2. Prevalence and degree of hearing loss as a function of age across individual frequencies

In the previous section hearing loss of participants in the different age groups were described in terms of the hearing-loss categories. Bilateral median thresholds (per participant) were calculated per frequency for each age group for participants in Noise Group 1 and are shown in figure 5.9. Since results were very similar for the No Noise Group, results for this group were not shown in a figure but were compared to that of Noise Group 1 in table 5.6.

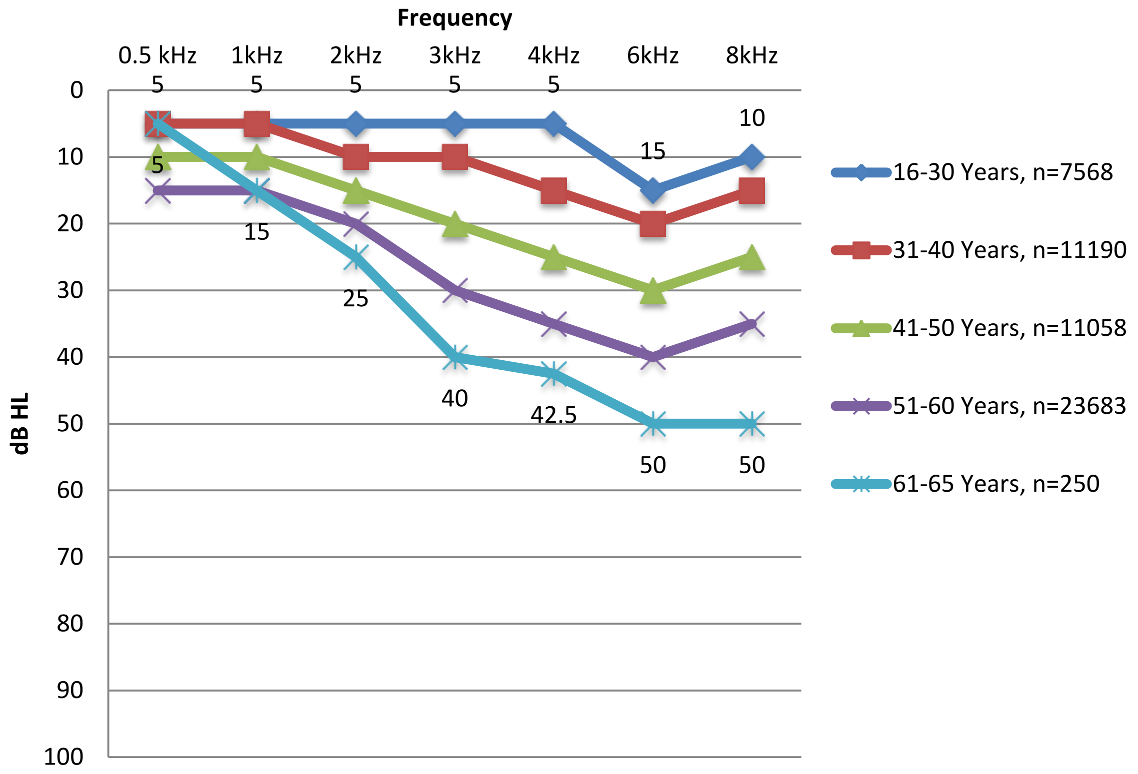


Figure 5-9 Median thresholds (in dB HL) per frequency for each age category for Noise Group 1 (N=33961)

Figure 5.9 demonstrates clearly how the median threshold values across all frequencies calculated for the different age groups for participants in Noise Group 1 became progressively more elevated as the participants' ages increased. This tendency was also seen in the results for the No Noise Group and is shown in comparison to Noise Group 1 in table 5.6. This increase in hearing thresholds grew with higher frequencies. For example, the difference between the median thresholds of the participants in the 61 to 65 age group versus the 16 to 30 age group were 0 dB at 0.5 Hz, 10 dB at 1 kHz (elevated values for the older age group at all frequencies), 20 dB at 2 kHz, 35 dB at 3 kHz, 38.5 at 4 kHz, 35 dB at 6 kHz and 40 dB at 8 kHz.

Based on the notch criteria of Coles and colleagues (Coles, Lutman, & Buffin, 2000), defined as a high-frequency notch where the hearing threshold at 3, 4, and/or 6 kHz is at least 10 dB greater than at 1or 2 kHz and at least 10 dB greater than at 6 or 8 kHz, a notch was observed in all average age groups except the 61 to65 year group at 6 kHz (10 dB notch). Between the consecutive age groups the greatest difference was 10 dB at 4 kHz between the 16 to 30 years and the 31 to 40 years group, 10 dB at 3,4,6 kHz between the 31 to 40 years and the 41 to 50 years groups, 10 dB at 3,4, and 6 kHz between the 41 to 50 years and the 51 to 60 years group and 10 dB at 3 and 6 kHz between the 51 to 60 years and the 61 to 65 years groups.

In order to compare the median thresholds (bilateral) of the different age groups for Noise Group 1 versus the No Noise Group these medians were tabled in table 5.6. Median thresholds values for the No Noise Group participants for the different age groups are indicated. Where these thresholds differed from those of Noise Group 1, the Noise Group 1 median values are indicated.

Table 5-6 Median threshold values (in dB HL) per frequency for the No Noise Group categorised by age groups, Noise Group 1 values show where a difference exists between the values of the two groups (Noise Group 1: Underground occupational noise ≥ 85 dB A TWA , No Noise Group: No known occupational noise)

	Noise Group 1: (N=33961)	No Noise Group: (N=6194)
No Noise Group values < Noise Group 1 values	16 to 30 years, n=7568	16 to 30 years, n=1623
	31 to 40 years, n=11190	31 to 40 years, n=2327
No Noise Group values > Noise Group 1 values	41 to 50 years, n=11058	41 to 50 years, n=1696
	51 to 60 years, n=3683	51 to 60 years, n=492
	61 to 65 years, n=250	61 to 65 years, n=24

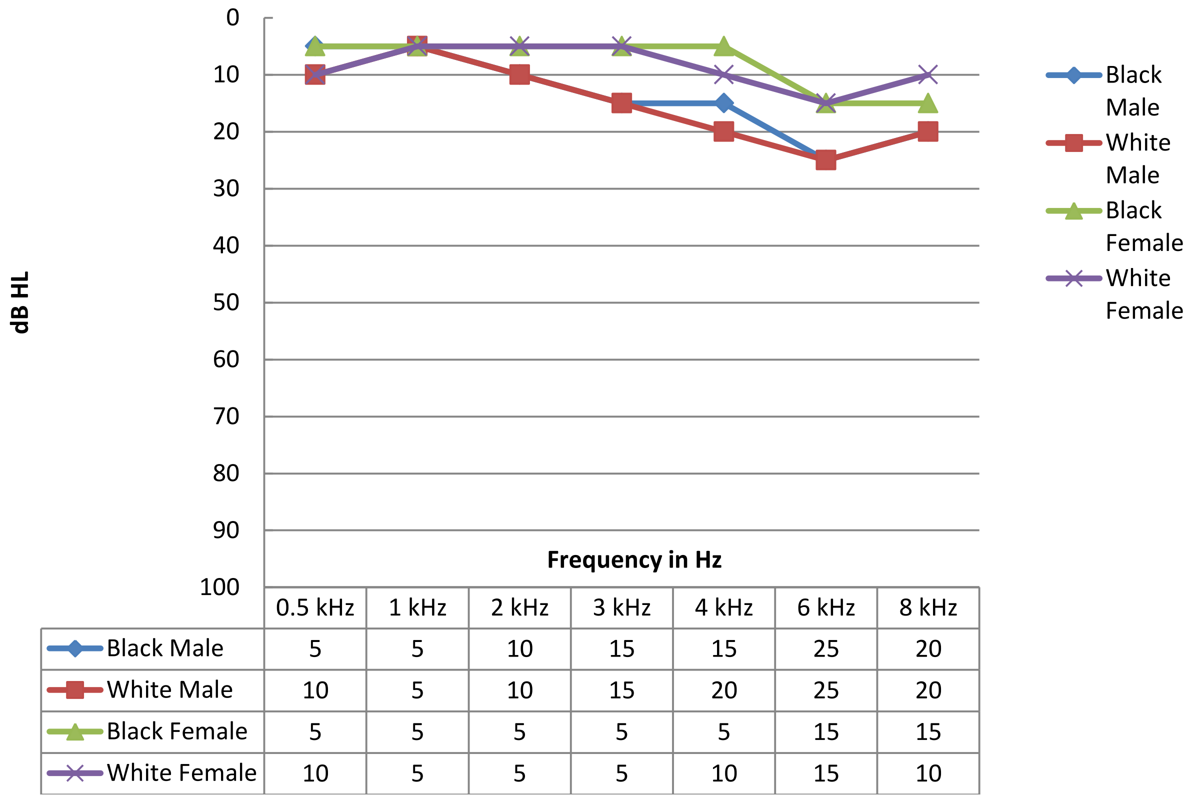
	Median values for thresholds (dB HL) per frequency for No Noise Group (Noise Group 1 median thresholds in brackets)						
	0.5 kHz	1 kHz	2 kHz	3 kHz	4 kHz	6 kHz	8 kHz
16 to 30 years	5	5	5	5	5	15	10
31 to 40 years	5	5	10	10	15	20	15
41 to 50 years	10	10	15	20	25	30	25
51 to 60 years	10	15	25 (20)	30	35	35 (40)	35
61 to 65 years	20 (5)	10	20 (25)	25 (40)	35 (42)	35 (50)	40 (50)

Table 5.6 shows that the median threshold values for Noise Group 1 versus the No Noise Group participants are very similar. The age group where differences were mostly observed was the age group 61 to 65 years. All the higher frequencies (2, 3, 4, 6 and 8 kHz) had higher values for Noise Group 1 than for the No Noise Group (with the largest differences (15 dB) observed at 3 and 6 kHz.

Noise Group 1 and the No Noise Group differed significantly (worse for Noise Group 1) with respect to the median for all frequencies in an ANCOVA after adjusting for age. All p-values were less than 0.01. (0,5kHz, p=0,0013; 1kHz, p=0,000; 2kHz, p=0,000; 3kHz, p=0,000; 4kHz, p=0,000; 6kHz, p=0,000; 8kHz, p=0,001).

5.3.3. Prevalence and degree of hearing loss as a function of race and gender across individual frequencies

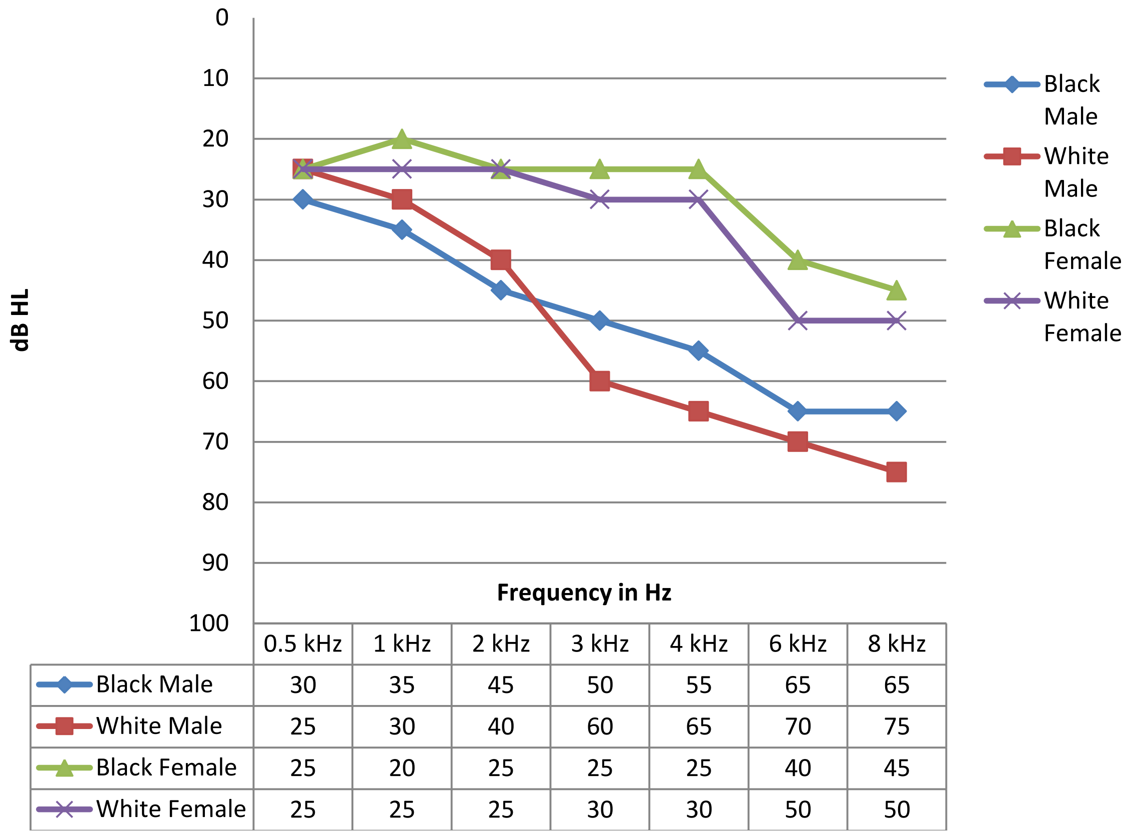
In order to describe the prevalence of hearing loss and the degree thereof as a function of race and gender, the cohort of gold miners were categorised into the following categories: black male, white male, black female and white female. For the different groups, dichotomised into Noise Group 1 and the No Noise Group, median and 95th percentile values for the thresholds per frequency were calculated. Figure 5.10 shows the median threshold values for the different race and gender groups for Noise Group 1 (occupational noise exposure ≥ 85 dB A, TWA). Figure 5.11 demonstrates the 95th percentile values for these thresholds. Table 5.6 aids comparison between the median and 95th percentile threshold values for participants in these race and gender groups between Noise Group 1 and the No Noise Group (no known occupational noise exposure).



	0.5 kHz	1 kHz	2 kHz	3 kHz	4 kHz	6 kHz	8 kHz
Black Male	5	5	10	15	15	25	20
White Male	10	5	10	15	20	25	20
Black Female	5	5	5	5	5	15	15
White Female	10	5	5	5	10	15	10

Figure 5-10 Median values for thresholds in dB HL per frequency for participants in Noise Group 1 categorised by race and gender (Black Male, n=35866; White Male, n=5374; Black Female, n=1698; White Female, n=434)

As demonstrated by figure 5.10, the largest differences were observed between the male and female groups, especially in the high frequencies. A 10 dB difference was observed between the median thresholds for the male versus female groups at 3, 6 and 8 kHz and 20 dB at 4 kHz. The largest difference between the “best” median threshold (black female) and the most elevated median thresholds (white male) were observed at 4 kHz, a difference of 15 dB HL (white male, 20 dB HL versus black female, 5 dB HL). The median thresholds for the females were grouped close together, with the only difference between white and black females at 0.5, 4 and 8 kHz, 5 dB being more elevated for the white females in all instances. The median thresholds for men (black and white) were also grouped close together. White males showed 5 dB higher thresholds than the black males at 5 and 4 kHz.



	0.5 kHz	1 kHz	2 kHz	3 kHz	4 kHz	6 kHz	8 kHz
Black Male	30	35	45	50	55	65	65
White Male	25	30	40	60	65	70	75
Black Female	25	20	25	25	25	40	45
White Female	25	25	25	30	30	50	50

Figure 5-11 95th Percentile values for thresholds in dB HL per frequency for participants in Noise Group 1 categorised by race and gender (Black Male, n=17933; White Male, n=; Black 2687Female, n=849; White Female, n=217)

When 95th percentile values of the threshold distributions were used (for the 5% with the highest thresholds) differences between the different gender and race groups (Noise Group 1) were more pronounced than for the median threshold values (shown in figures 5.10 and 5.11). As with the median threshold values the largest thresholds (95th percentiles shown in figure 5.11) were observed for white males, followed by black males, white females and black females (best thresholds). The largest difference was measured at 4 kHz between the white males (65 dB HL) and the black females (25 dB HL). 95th Percentiles for the females showed a difference of between 5 and 10dB between the white and black females (black females had the better thresholds). Between the male groups 95th percentiles also differed between 5 and 10 dB across the frequency range. Larger differences up to 40dB were observed between the male and female groups, with the female thresholds lower than those of the male groups. After correcting for age through ANCOVA, pair wise comparisons (F-test) indicated a significant difference between the black male group and white male group (p=0.00) for the low and high frequencies, with thresholds for the low frequencies (0.5, 1 and 2 kHz) significantly worse for black males and high frequencies (3, 4, 6 and 8 kHz) significantly better for black males compared to white males.

Threshold distributions for the same race and gender groups for the No Noise Group revealed the same tendency for males to have elevated thresholds compared to females. This was also evident for white males having elevated threshold distributions (median and 95th percentile values) compared to black males in the same way as for white females and black females. To aid comparison between the two noise groups table 5.7 summarises these differences.

Table 5-7 Median and 95th percentile values for thresholds (in dB HL) across frequency for the No Noise Group according to gender and race. Noise Group 1 values were included when a difference existed between the two groups (*Noise Group 1: Underground occupational noise ≥85 dB A TWA; the No Noise Group: No known occupational noise)*

░ Noise Group 3 values < Noise Group 1 values ▓ Noise Group 3 values > Noise Group 1 values	Noise Group 1: Black Male (n=17933) White Male (n=2687) Black Female (n=894) White Female (n=217)	No Noise Group: Black Male (n=2790) White Male (n=508) Black Female (n=314) White Female (n=42)

	Median values for thresholds (dB HL) per frequency for the No Noise Group (Noise Group 1 median thresholds in brackets)						
	0.5 kHz	1 kHz	2 kHz	3 kHz	4 kHz	6 kHz	8 kHz
Black Male	5	5	10	░ 10 (15)	15	░ 20 (25)	20
White Male	10	5	10	15	20	░ 22.5 (25)	20
Black Female	5	5	5	5	5	15	15
White Female	░ 5 (10)	5	5	5	5	15	10
	95th Percentile values for thresholds (dB HL) per frequency for the No Noise Group (Noise Group 1 95th Percentile values in brackets)						
	0.5 kHz	1 kHz	2 kHz	3 kHz	4 kHz	6 kHz	8 kHz
Black Male	30	35	░ 40 (45)	50	55	░ 60 (65)	░ 60 (65)
White Male	25	░ 25 (30)	40	60	▓ 70 (65)	70	░ 70 (75)
Black Female	25	20	25	25	25	40	░ 50 (45)
White Female	░ 20(25)	░ 20 (25)	25	░ 25 (30)	30	50	░ 35 (50)

From table 5.7 it is clear that all differences observed between the different noise groups revealed elevated thresholds for Noise Group 1 compared to the No Noise Group, apart from the 95th percentile value for white males, Noise Group 1, white male; 65 dB HL versus the No Noise Group, white male; 70 dB HL. Other differences in median threshold distributions were observed between the black and white male groups of Noise Group 1 and the No Noise Group at 6 kHz. The only thresholds that differed for all race and gender groups at a selected frequency were the 95th percentile values at 8 kHz, with the largest difference, Noise Group 1 15 dB higher than for the No Noise Group, observed for the white female group.

5.3.4. Prevalence and degree of hearing loss as a function of race and gender by pure tone averages

The high and low frequency averages (HFA346 and the LFA512) of the thresholds of the different race and gender groups were compared in terms of median and 95th percentile values for these groups (figures 5.12 and 5.13).

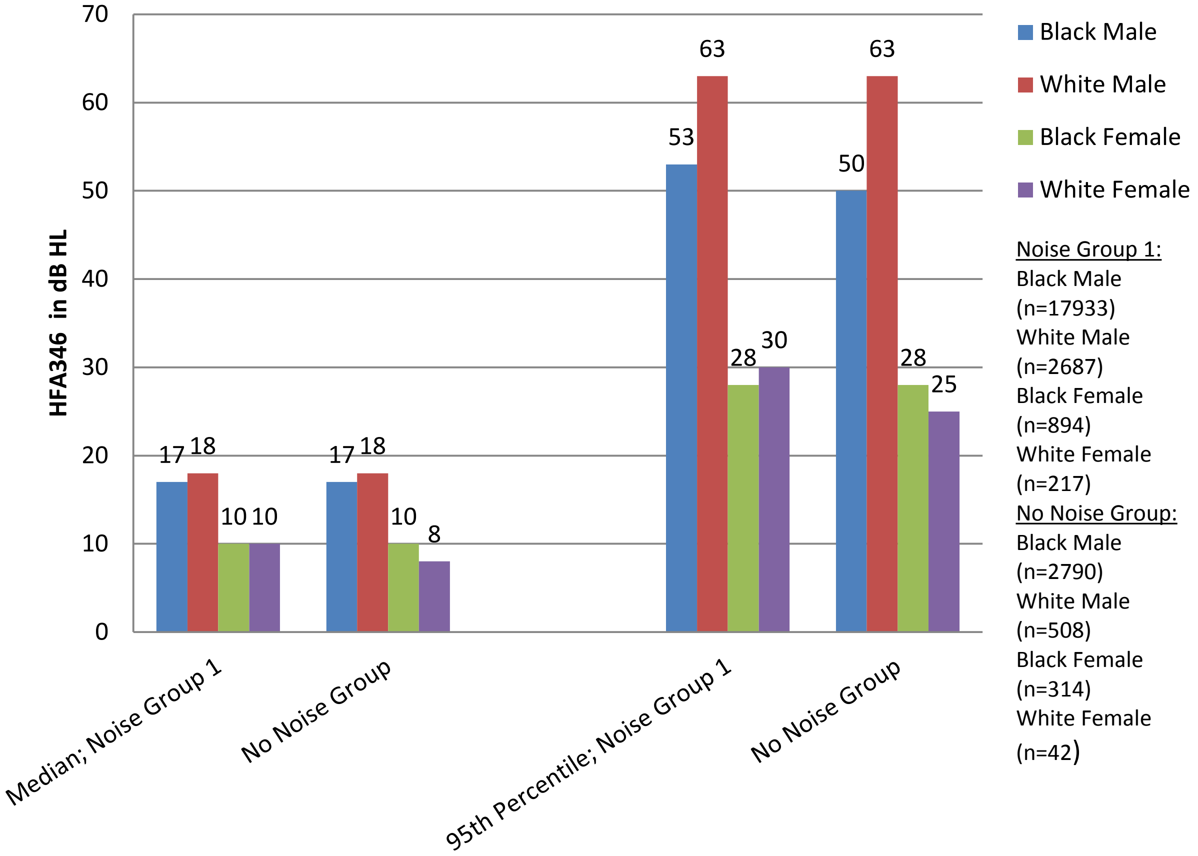


Figure 5-12 Median and 95th percentile values of the high frequency average for thresholds at 3, 4, and 6 kHz, (HFA346) compared for the different race and gender groups within the different Noise Groups

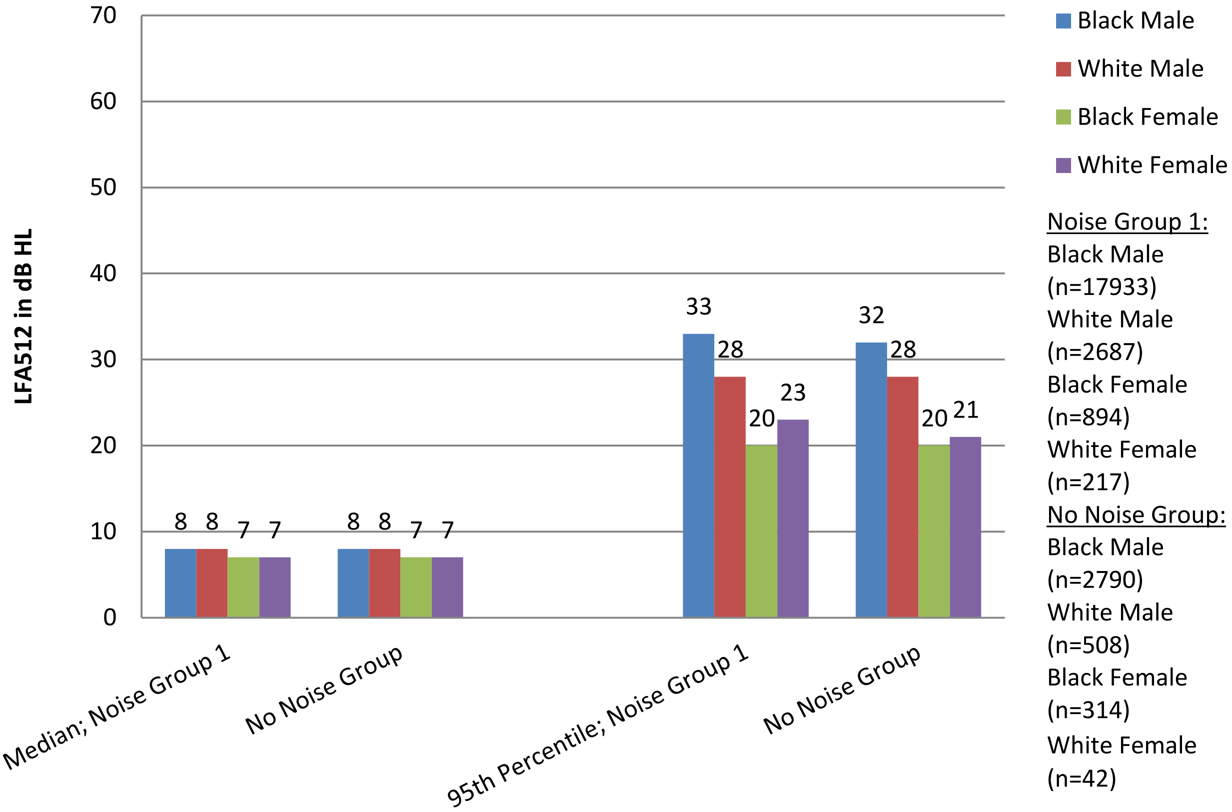


Figure 5-13 Median and 95th percentile values of the low frequency average for thresholds at 0,5, 1, 2 kHz, (LFA512) compared for the different race and gender groups within the different Noise Groups frequency (Noise Group 1: Underground occupational noise ≥85 dB A TWA (n= 33961); No Noise Group: No known occupational noise (n=6194))

From figures 5.12 and 5.13 it is clear that the median and 95th percentile values for the HFA346 (figure 5.12) was larger (more elevated) for all groups that the LFA512 values (figure 5.13). Differences between results for the two noise groups were very small (>5 dB) for all race/gender groups. The difference between the median values for the HFA346 and the LFA512 for the male groups (white and black) and the female groups (black and white) was larger for the HFA346 values than for the LFA512 values. The HFA346 median values for females were ≈8dB better for females than for males compared to the 1 dB difference for male and female median values for the LFA512 results. This was true for both noise groups. A very large difference was observed between the male and female groups for the 95th percentile values for the HFA346. The female 95th percentile values (black and white) were between 20 and 30 dB better (25-30 dB HL) than those of the male groups, black and white, 50-63 dB HL, for both noise groups.

For 95th percentile values, HFA346, the white male group showed poorer threshold averages than the black male group (Noise Group 1 and the No Noise Group). When comparing the HFA346 and the LFA512 values a reverse trend is seen in terms of the 95th percentile values for the black and white males, where the black males had a 10 dB better HFA346 value (53 dB HL) than the white males (63 dB HL) but the black males had a 5 dB more elevated LFA512 value (33 dB HL) than the 95th percentile value for the LFA512 for white males (28 dB HL). This reverse trend was apparent for participants in the male groups in Noise Group 1 and the No Noise Group.

5.4. Sub aim 3: Prevalence and degree of hearing loss as a function of occupation / noise-exposure level

In order to understand the effect of the occupational noise-exposure level as well as the exposure level over time participants in Noise Group 1 were divided into different age groups and then further divided according to their working years (exposed to noise levels ≥ 85 dB A TWA). As exposure levels differ between the participants within the broader noise groups participants were divided into groups as defined by the mine as homogeneous exposure groups (HEG) in terms of the exposure level and durations. Two groups were selected because of their homogeneous exposure levels. These groups were the drillers (noise exposure ≥ 90 dB A) and the administration group, including accountants and administrative workers with no known occupational noise exposure.

5.4.1. Prevalence and degree of hearing loss as a function of noise exposure time by age group and across individual frequencies

Participants in Noise Group 1 were divided into different age groups and then further divided into the number of years that they had been working. The working years were categorised into 5 year intervals and data of participants for which the “engage date” (date of commencement of work) were available were included in the analyses. The duration of this working period is based on the assumption that hearing thresholds (±10 dB HL) are stable over a period of 5 years for a similar level of noise exposure or a reduction of such exposure (Picard, et al., 2008). The number of participants in each of the age groups and each of the working years' categories are tabled in table 5.8 below.

Table 5-8 Number of participants in each age group, categorised according to their working years (Noise Group 1: Underground occupational noise ≥85 dB A TWA)

Working years	16 to 30yrs	31 to 40yrs	41 to 50yrs	51 to 60yrs	61 to 65yrs	Total N
0 - 5yrs	3575	2965	1805	450	60	8855
>5 - 10yrs	554	1610	1098	253	13	3528
>10 - 15yrs	25	1627	1011	213	7	2883
>15 - 20yrs	-	770	3087	1228	44	5134
Total	4154	6972	7001	2144	124	20400

Median values for hearing thresholds across the frequency range were calculated for each "working years" category and are shown per age group in figures 5.14 to 5.18.

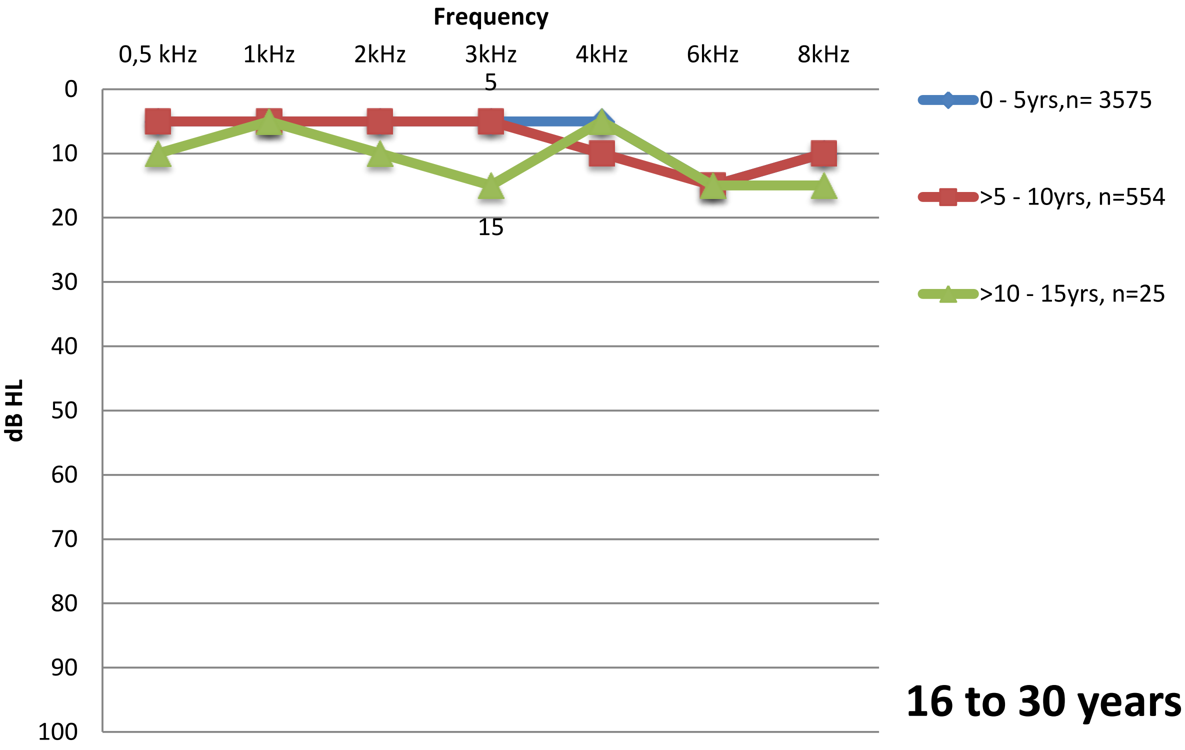


Figure 5-14 Median thresholds per frequency for the age group 16 to 30 years categorised by their working years (Noise Group 1, occupational noise 85 dB TWA)

In the age group 16 to 30 years (figure 5.14) the largest difference in median thresholds of 10 dB were observed at 3 kHz between the group who worked between 0 to 5 years (median= 5 dB HL) compared to the group who had been working between 10 and 15 years (median= 15 dB HL). All other differences were 5 dB or less.

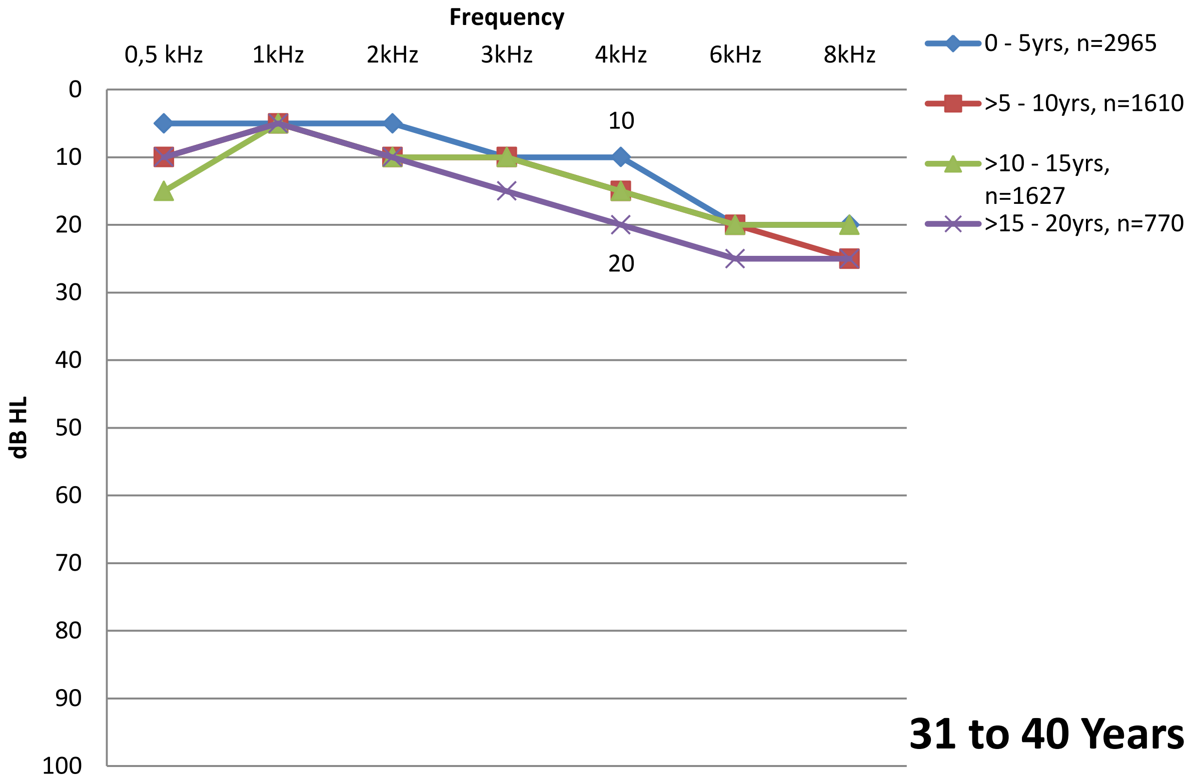


Figure 5-15 Median thresholds per frequency for the age group 31 to 40 years categorised by their working years (Noise Group 1, occupational noise 85 dB TWA)

Median threshold values for the age group 31 to 40 years (figure 5.15) showed the smallest values and better thresholds for the group that had worked between 0 and 5 years, followed by the groups who had worked >5 to 10 years and >10 to 15 years. The median audiograms for these two “working years” categories are very similar, thresholds at 0,5 and 8 kHz differing with 5 dB. The most elevated median thresholds (greatest values) were observed for the 15 to 20 “working years” category. The largest difference in median thresholds (10 dB) was calculated at 4 kHz between the 0 to 5 “working years” category and the 15 to 20 “working years” category.

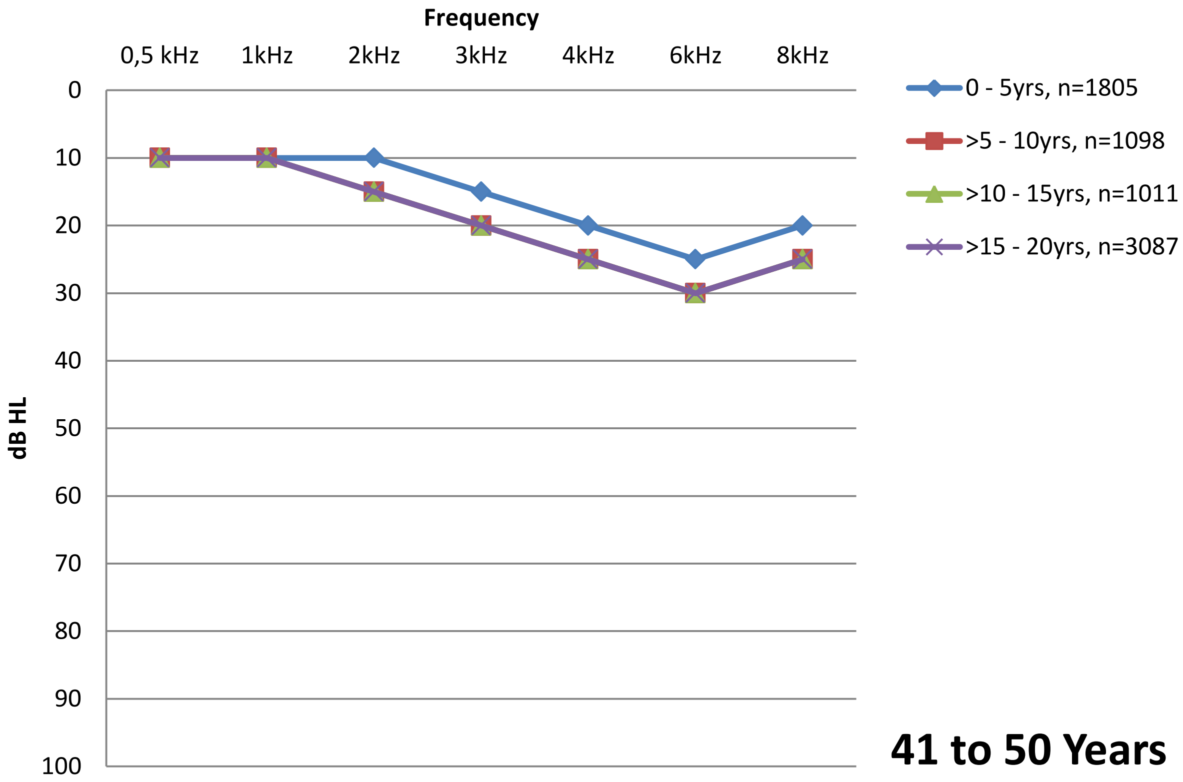


Figure 5-16 Median thresholds per frequency for the age group 41 to 50 years categorised by their working years (Noise Group 1, occupational noise 85 dB TWA)

For the age group 41 to 50 years (figure 5.16) no differences were observed for the median thresholds of workers who had worked between 5 and 20 years. The thresholds at all three “working years” categories (>5 to 10yrs, >10 to 15yrs, and >15 to 20yrs) showed a 5 dB difference in median thresholds across the frequencies between 1 and 8 kHz for the workers who had worked less than 5 years. Compared to median thresholds for the age groups 16 to 30 and 31 to 40 these groups' thresholds were poorer as can be expected based on the increase in age (compared with figure 5.16 and 5.17).

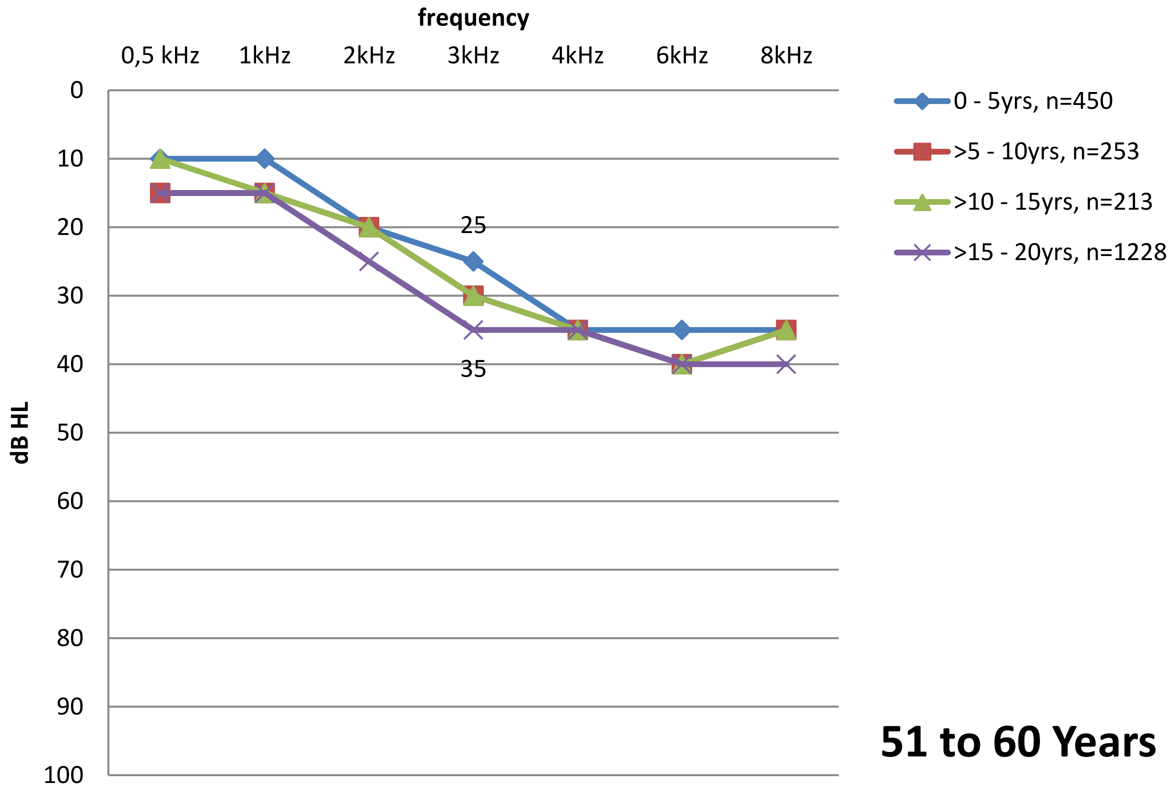


Figure 5-17 Median thresholds per frequency for the age group 51 to 60 years categorised by their working years (Noise Group 1, occupational noise 85 dB TWA)

As was seen in figure 5.14 results shown in figure 5.17 revealed the largest difference in median thresholds of 10 dB between the “working years’ categories 0 to 5 years and 15 to 20 years at 3 kHz. It is clear from figure 5.20 that median thresholds got increasingly more elevated as the working years increased.

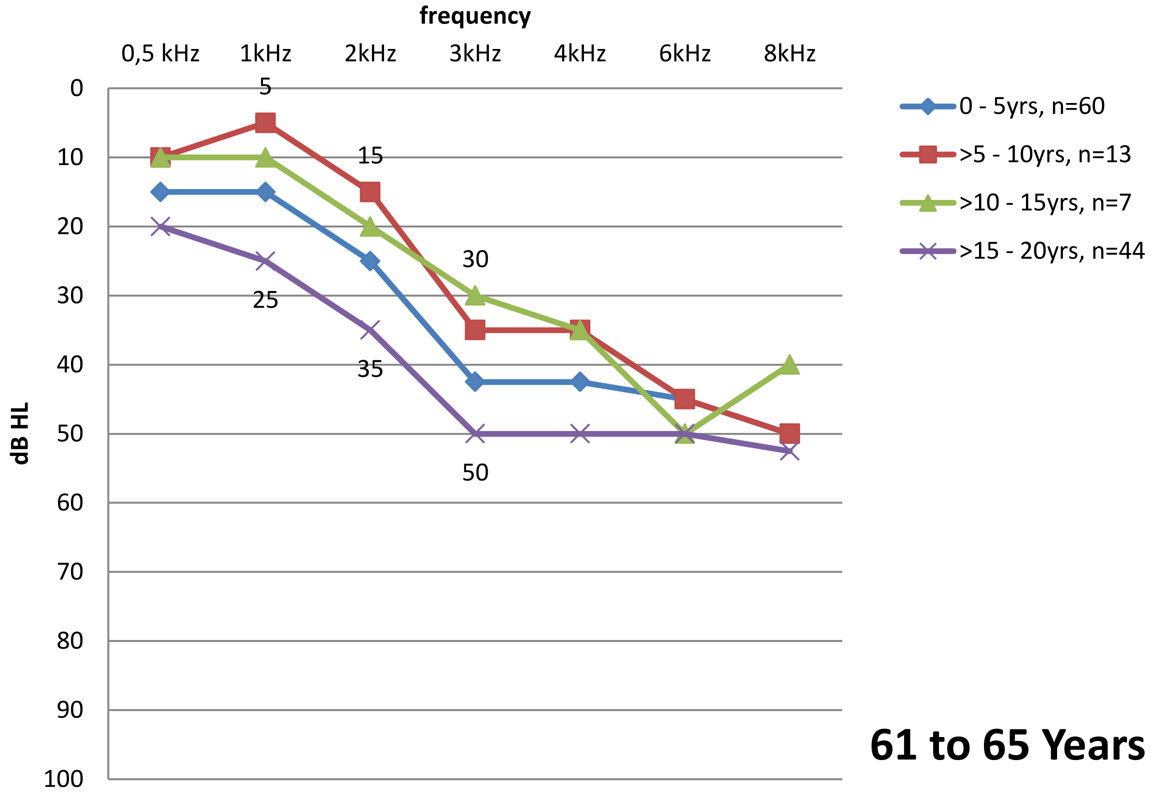


Figure 5-18 Median thresholds per frequency for the age group 61 to 65 years categorised by their working years (Noise Group 1, occupational noise 85 dB TWA)

Differences between the participants in the different "working years" categories were the most obvious for the age group 61 to 65 years (figure 5.18) compared to the other age groups (figure 5.14-5.18). As was shown in figure 5.14 and 5.17 the largest difference (20 dB) in this age group was observed at 3 kHz between the workers who had less than 5 years' experience (30 dB HL) and the workers with more than 15 years' experience (50 dB HL). 20 dB differences were also observed at 1 and 2 kHz between the group with 5 to 10 years' working experience and the group with more than 15 year's working experience.

5.4.2. Prevalence and degree of hearing loss as a function of noise- exposure level for homogenous exposure groups across individual frequencies

To investigate the effect of noise exposure on the hearing of miners, sub groups were defined within Noise Group 1 and the No Noise Group. South African goldmines define homogenous exposure groups (HEG) as groups of workers where occupational noise exposure, in terms of duration and intensity, are the same. Drillers in South African goldmines are typically exposed to occupational noise levels of between 90 and 130 dB A (Franz & Phillips, 2001). The administration group are administrative workers who have not previously been exposed to occupational noise. This group is defined as “admin”. Figures 5.19 and 5.20 show the number of participants for these two HEGs (administration and driller) categorised by race, gender, and age group.

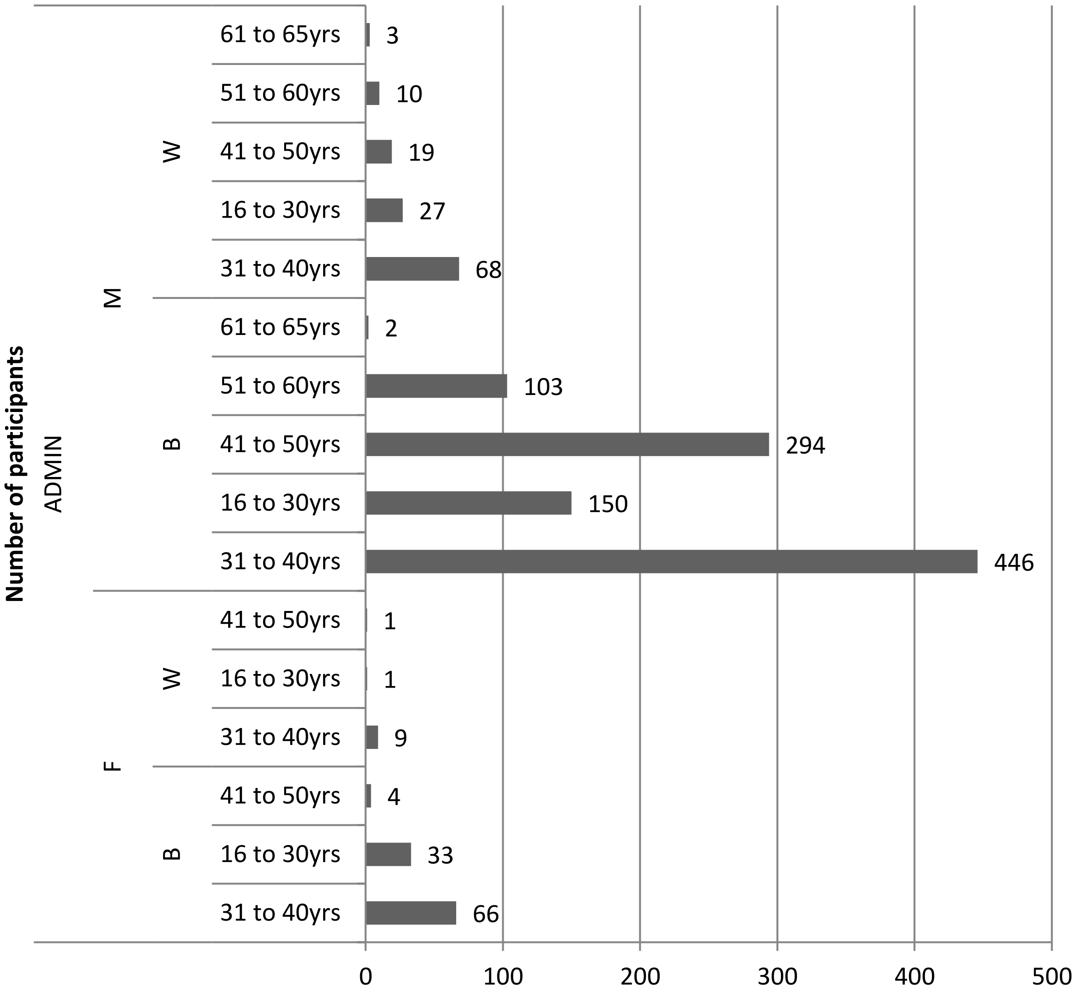


Figure 5-19 Number of participants for the administration group per race and gender and age category

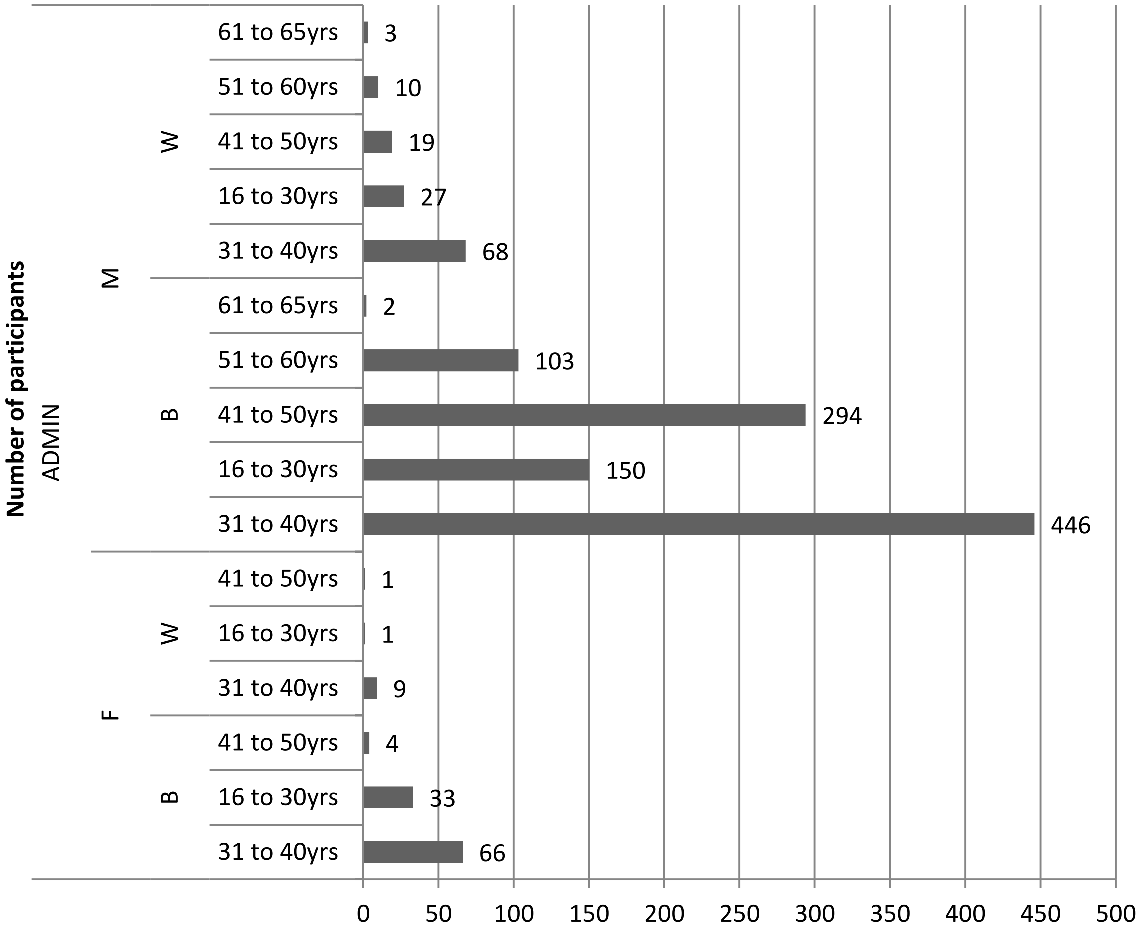


Figure 5-20 Number of participants for the driller group per race and gender group

From figures 5.19 and 5.20 it is clear that the driller as well as administration group were represented mostly by black male participants. In the administration group most of these black, male participants were between 31 and 40 years followed in numbers by participants between 41 and 50 years. In the driller group most black, male participants were between 41 and 50 years followed in numbers by participants between 51 and 60 years.

In figure 5.21 median and 95th percentile values of these two HEGs (all participants in the groups) for thresholds across the frequency range were compared. As seen in the previous two figures (figures 5.19 and 5.20) it is clear that the participants in the driller group were slightly older that those in the administration group and results in Figure 5.21 might be influenced. In figure 5.22 results (median and 95th percentile threshold values per frequency) for black, male participants in three age categories, 31 to 40 years, 41 to 50 years and 51 to 60 years were selected and shown. The other age categories had too little participants to compare results.

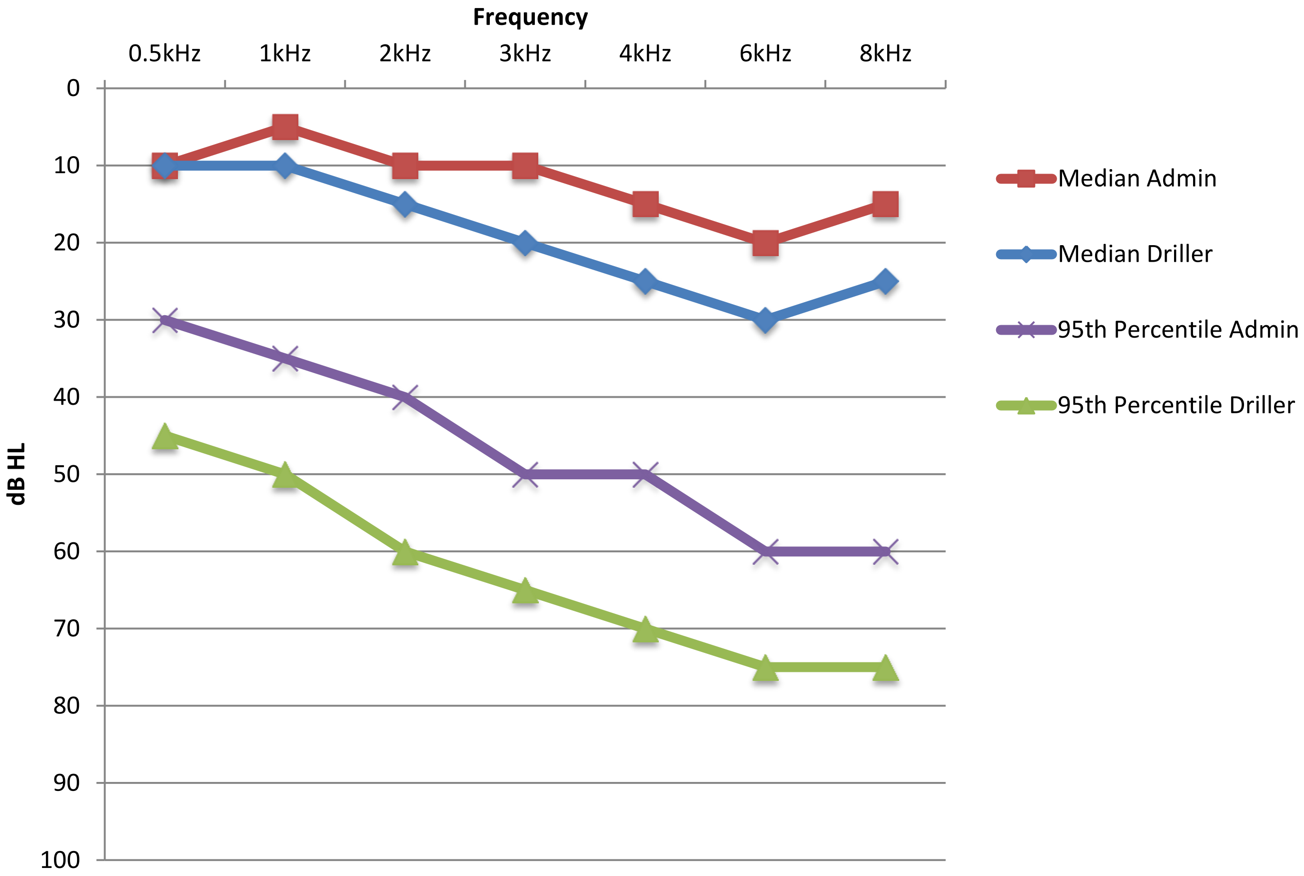


Figure 5-21 Median and 95 th Percentile values for thresholds (in dB HL) across the frequency range for homogenous exposure groups (HEGs); Drillers and Admininstration (Admin)

From figure 5.21 it is clear that median as well as 95th percentile values of hearing thresholds across the frequency spectrum are very different for the administration and driller sub groups. All values of the drillers were markedly more elevated (higher) than those for the administration group. In the frequency range from 3 to 8 kHz median thresholds for the drillers were 10dB more elevated than those for the administration group. 95th percentile values for drillers range between 45 dB HL and 75 dB HL compared to the 30 and 60 dB HL range for the administration group. Across the frequency spectrum drillers' thresholds (95th percentile) are approximately 20 dB more elevated than those of the administration group. When compared to the difference between median and 95th percentile values of Noise Group 1 compared to the No Noise Group, (see figures 5.5 and 5.6) the differences observed in figure 5.21 for these HEGs are much greater. As shown in figures 5.19 and 5.20 the administration and driller groups are not the same in terms of the age, gender and race distribution and results might be influenced by these factors.

In order to address these differences a sub group within the driller and administration groups of similar age, gender, and race was selected to aid comparison. The sub groups (black, male participants in different age categories) were selected based on the number of available participants (see figure 5.19 and 5.20). In both the driller and administration sub groups median and 95th percentile values for thresholds across the frequency spectrum were calculated for black, male participants within the age groups 31 to 40 years, 41 to 50 years, and 51 to 60 years. These values are shown in figures 5.22 and 5.23.

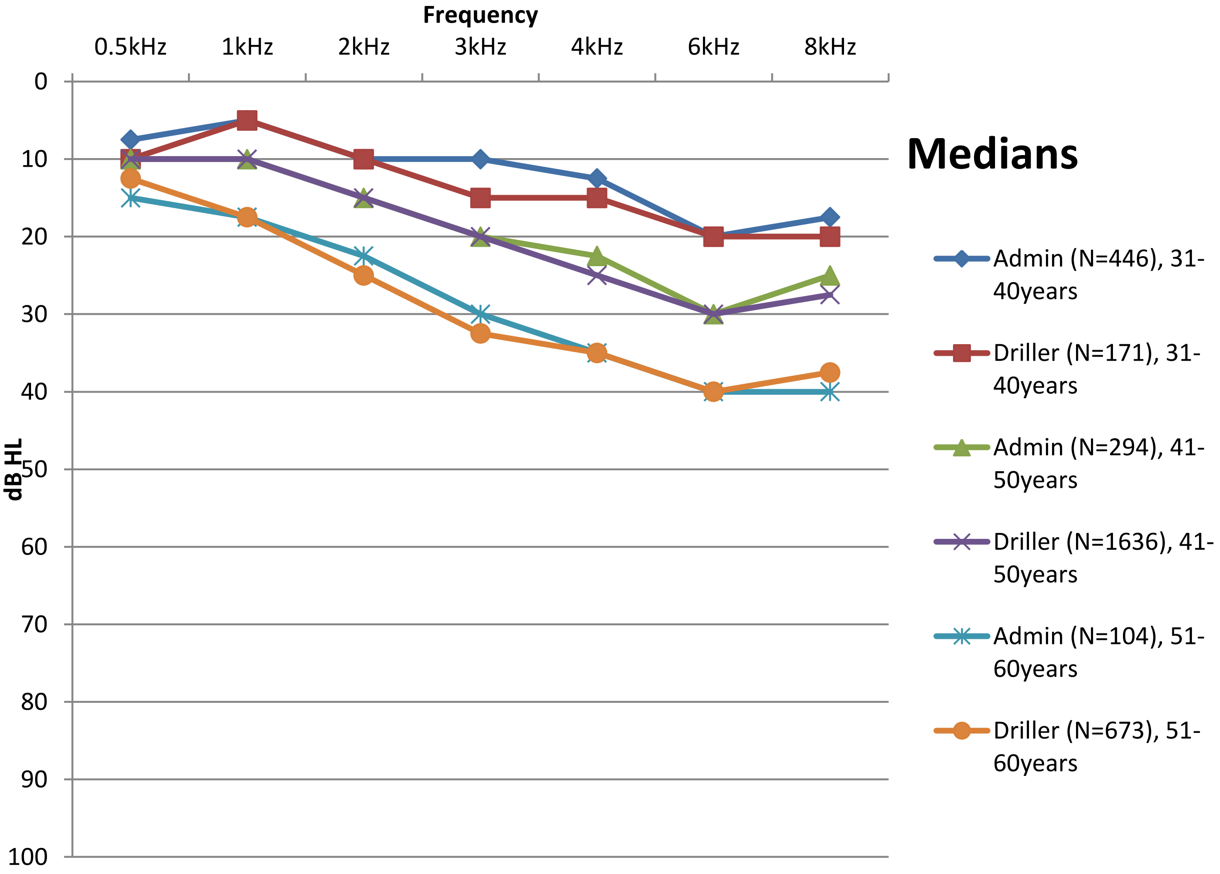


Figure 5-22 Median values for thresholds (in dB HL) across the frequency range for black, male participants in the Driller and Administration (admin) groups, for ages 31 to 40 years, 41 to 50 years, and 51 to 60 years

The largest difference between the median values for the administration and driller groups (figure 5.22) was observed in the black, male group for the age group 31 to 40 years at 3000Hz (driller group's value 5 dB more elevated than for the administration group). Differences between median threshold values for the sub groups 41 to 50 years and 51 to 60 years were less than 5 dB (not clinically significant). Figure 5.23 shows the 95th percentile values for these sub groups.

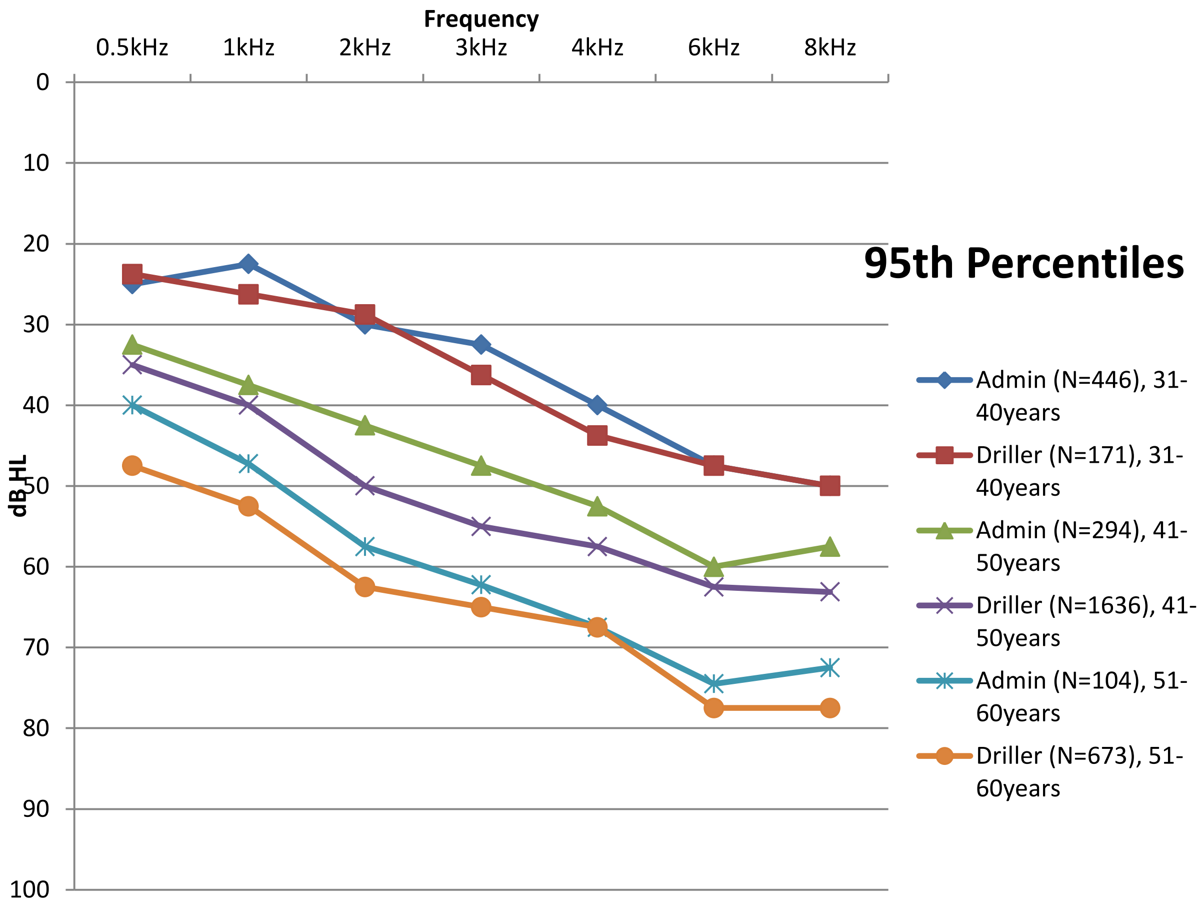


Figure 5-23 95th Percentile values for thresholds (in dB HL) across the frequency range for Black, Male participants in the Driller and Administration (admin) group, for ages 31 to 40 years, 41 to 50 years, and 51 to 60 years

The differences between 95th percentile values for the driller and administration groups shown in figure 5.23 were smaller than those observed in figure 5.21 when age, gender, and racial differences were not taken into account. The largest differences (between driller and administration groups) were observed for the black, male participants between 41 and 50 years at 2 and 3 kHz, with 95th percentile values for drillers more than 5 dB more elevated than for the administration group.

Based on the 95th percentile values for the black male participants in the administration and driller groups it is observed that the thresholds values of these two groups came closer in values as the frequencies became higher.

In an ANCOVA the administration and driller groups differed significantly (driller group worse results) with respect to the mean LFA512 and HFA346 after adjusting for age. The p values for the LFA512 was p=0.0004 and the HFA346 was p=0.069.

5.5. Sub aim 4: The combined effect of various biographical, environmental and work-related variables on hearing status

To asses the combined effect of various variables on the hearing status of goldminers, threshold distributions were compared to demographically matched control groups to evaluate if hearing thresholds are typical for a matched demographic group. Comparisons with a matched demographic group can be used to describe whether a person’s status is typical (Flamme, et al., 2011). A synthesis of reported effects culminated in the development of the ISO 1990:1999 and the nearly identical ANSI S3.44 (1996) guidelines. Both international (ISO 1990:1999) and United States of America (ANSI S3.44-1996) standards describe the distributions of hearing thresholds (10th, 50th, and 90th percentiles, for 0,5 to 6 kHz) associated with age and gender. ISO 1990:1999, Annex B of ISO 1990:1999, was used to compare data with as this annex includes some people with occupational noise exposure, but is otherwise more representative of the general population (Dobie, 2006). In a study by (Hoffman, Dobie, Ko, Themann, and Murphy (2010) hearing threshold data from the nationally representative survey in the United States (National Health and Nutrition Examination Survey, 1999–2004) were presented as a possible replacement for Annex B in ISO 1990:1999 and ANSI S3.44. Age groups as defined by the ISO 1990:1999 are 25 to 34 years, 35 to 44 years, 45 to 54 years and 55 to 64 years. Annex B (ISO 1990:1999) distributions represent better ear hearing levels. For these comparisons the best (lowest) threshold across ears was selected at each frequency (Flamme, et al., 2011). The ISO 1990:1999 does not stratify the results for the different race groups. ANSI S3.44 offers Annex C in addition to Annex A and Annex B which gives threshold distributions for people who have never had noisy jobs (Hoffman, Dobie, Ko, Themann, & Murphy, 2010). Data in this Annex C are categorised into different race and gender categories. Hearing thresholds of the cohort (with daily noise exposure above 85 dB A as well as the No Noise group) were compared to these standards. Annex B distributions represent better ear hearing levels. For these comparisons the best (lowest) threshold across ears was selected at each frequency (Flamme, et al., 2011). Annex C (ANSI S3.4, 1996) distributions represent binaural averages and these were calculated and used for comparisons. It is also important to note that the current study used the conventional method for calculating the median, where for example the median of a group of 15 would be simply the 8th-ranked value. The ISO 1990:1999, ANSI S3.44 (1996) and the Hoffman, Dobie, Ko, Themann & Murphy (2010) studies calculated the median for grouped data, assuming that the cases in each 5-dB interval are evenly distributed (Dobie, 2006). The five “15 dB” cases would be redefined as 13, 14, 15, 16, and 17 dB and the five “20 dB” cases as 18, 19, 20, 21, and 22 dB. The median is the 8th-ranked case in this new distribution (18 dB).

Table 5.9 shows the number of subjects included in each of the age groups as defined by the ISO 1990:1999.

Table 5-9 Number of participants of the study per age group (as defined by ISO 1990:1999)

Age category using ISO age groups	N	Percentage of available sample (%)
25 to 34yrs	15 770	30,04%
35 to 44yrs	19 279	36,72%
45 to 54yrs	13 786	26,26%
55 to 64yrs	3 662	6,98%
Total	52 497	100%

Table 5-10 Hearing-threshold level (in dB HL) for the No Noise Group (no known occupational noise exposure) for men and female of different ages

	Hearing-threshold level (dB HL) Age* No Noise Group (no occupational noise exposure)																			
	30					40					50					60				
Percentiles																				
Frequency (Hz)	5	0	50	90	95	5	10	50	90	95	5	10	50	90	95	5	10	50	90	95
Men	n= 953					n=1205					n=829					n=150				
500	0	0	5	10	15	0	0	5	15	20	0	0	5	20	25	0	0	10	30	35
1000	0	0	5	10	15	0	0	5	15	20	0	0	5	25	30	0	5	10	40	45
2000	0	0	5	15	20	0	0	5	20	25	0	0	10	35	40	5	5	20	45	55
3000	0	0	5	15	20	0	0	10	25	35	0	5	15	45	50	5	10	25	55	60
4000	0	0	5	20	25	0	0	10	30	40	5	5	20	45	55	10	10	32.5	60	65
6000	0	0	10	25	30	5	5	20	35	45	5	10	25	50	55	15	15	35	65	70
8000	0	0	10	25	30	0	0	15	35	50	5	5	20	50	55	10	10	30	62.5	70
Female	n=157					n=129					n=38					n=no data				
500	0	0	5	15	15	0	0	5	15	15	0	0	5	20	45					
1000	0	0	0	10	15	0	0	5	10	15	0	0	5	20	35					
2000	0	0	0	10	15	0	0	5	15	15	0	0	10	20	30					
3000	0	0	0	10	20	0	0	5	15	15	0	0	5	25	25					
4000	0	0	5	10	20	0	0	5	15	15	0	0	5	25	30					
6000	0	0	5	25	30	0	0	10	20	25	0	5	15	30	40					
8000	0	0	5	20	30	0	0	10	25	25	0	0	10	40	50					

*Age is grouped in 10yr intervals, that is, ‘30’ represents ages 25 to 34 yrs, etc.

Table 5-11 Hearing-threshold level (in dB HL) for Noise Group 1 (underground occupational noise exposure ≥ 85 dB A) for men and female of different ages

Hearing-threshold level (dB HL)
Age*
Noise Group 1(underground occupational noise exposure)

	30					40					50					60				
Percentiles																				
Frequency (Hz)	5	0	50	90	95	5	10	50	90	95	5	10	50	90	95	5	10	50	90	95
Men	n= 4718					n=7898					n=5728					n=1058				
500	0	0	5	10	15	0	0	5	15	20	0	0	5	20	25	0	0	10	25	35
1000	0	0	5	10	15	0	0	5	15	20	0	0	5	25	30	0	0	10	40	45
2000	0	0	5	15	20	0	0	5	20	30	0	0	10	35	45	0	5	20	45	55
3000	0	0	5	15	20	0	0	10	30	35	0	5	15	45	50	5	5	25	55	60
4000	0	0	5	15	20	0	0	10	35	40	0	5	20	45	55	5	10	30	60	65
6000	0	0	10	25	30	5	5	20	35	45	5	10	25	50	60	10	15	35	65	70
8000	0	0	10	25	30	0	5	15	35	45	5	5	20	50	60	5	10	35	65	75
Female	n=463					n=238					n=128					n=42				
500	0	0	5	15	20	0	0	5	15	15	0	0	10	20	25	5	5	10	25	25
1000	0	0	0	10	10	0	0	5	10	15	0	0	5	15	20	0	0	10	25	35
2000	0	0	5	10	15	0	0	5	15	20	0	0	5	20	35	5	5	10	25	35
3000	0	0	5	10	15	0	0	5	15	20	0	0	10	20	25	5	5	10	25	45
4000	0	0	0	10	15	0	0	5	15	15	0	0	10	20	30	0	5	10	25	65
6000	0	0	10	20	25	0	0	10	25	30	5	10	15	35	45	10	10	20	50	65
8000	0	0	10	25	30	0	0	10	25	35	5	5	15	40	50	5	5	25	60	70

*Age is grouped in 10yr intervals, that is, '30' represents ages 25 to 34 yrs, etc.
Thresholds differ from those of No Noise group (Table 5.10) where values of the Noise Group 1 is more than No Noise Group
Underline where No Noise group values are higher (worse) than Noise Group 1

Table 5-12Hearing-threshold level (in dB HL) for Administration Group (no known occupational noise exposure) for men and female of different ages

Hearing-threshold level (dB HL)
Age*
ADMINISTRATION

	30					40					50					60				
Percentiles																				
Frequency (Hz)	5	10	50	90	95	5	10	50	90	95	5	10	50	90	95	5	10	50	90	95
Men	N= 412					N=401					N=249					N=62				
500	0	0	5	10	15	0	0	5	15	20	0	0	10	20	25	0	5	10	35	45
1000	0	0	5	10	15	0	0	5	15	20	0	0	10	30	35	0	5	15	45	50
2000	0	0	5	15	20	0	0	5	20	25	0	0	15	35	45	5	5	20	55	60
3000	0	0	5	15	20	0	0	10	25	35	0	5	20	45	50	5	5	30	60	60
4000	0	0	5	20	25	0	0	10	30	35	5	5	20	45	55	10	10	35	65	65
6000	0	0	10	25	30	0	5	20	35	40	5	10	25	50	60	10	15	37.5	70	75
8000	0	0	10	25	30	0	0	15	35	40	5	5	20	50	55	10	10	40	65	80
Female	N=80					N=33					N=3					No data				
500	0	0	5	15	20	0	0	5	10	20	5	5	5	5	5					
1000	0	0	5	15	15	0	0	5	10	15	5	5	5	20	20					
2000	0	0	5	15	20	0	0	5	15	15	5	5	5	20	20					
3000	0	0	5	20	22.5	0	0	5	10	10	0	0	5	15	15					
4000	0	0	5	17.5	22.5	0	0	5	15	15	5	5	5	25	25					
6000	0	0	10	30	35	5	5	10	20	25	5	5	5	25	25					
8000	0	0	7.5	30	37.5	0	0	10	25	30	15	15	15	20	20					

*Age is grouped in 10yr intervals, that is, ‘30’ represents ages 25 to 34 yrs, etc.

Table 5-13 Hearing-threshold level (in dB HL) for drillers (underground occupational noise exposure ≥ 90 dB (A)) for men and female of different ages

Hearing-threshold level (dB HL)
Age*
DRILLER

	30					40					50					60				
	Percentiles																			
Frequency (Hz)	5	0	50	90	95	5	10	50	90	95	5	10	50	90	95	5	10	50	90	95
Men	n=256					n=1304					n=2277					n=505				
500	0	0	5	15	15	0	0	5	20	25	0	0	10	25	30	0	5	15	35	55
1000	0	0	5	10	10	0	0	5	20	35	0	0	10	35	45	0	0	15	50	55
2000	0	0	5	10	15	0	0	10	30	40	0	5	15	40	50	0	5	20	55	65
3000	0	0	5	15	15	0	0	10	35	45	0	5	20	45	50	5	5	30	60	70
4000	0	0	5	15	20	0	0	15	40	50	0	5	20	50	55	5	10	30	60	70
6000	0	0	10	25	30	5	5	20	40	55	5	10	25	50	60	10	15	35	75	85
8000	0	0	5	20	25	0	0	15	40	50	5	5	20	50	65	5	10	35	70	85
Female	n=46					n=38					n=53					n=17				
500	0	0	5	10	15	0	0	7.5	15	15	0	0	10	15	25	5	5	10	30	60
1000	0	0	5	10	10	0	0	5	10	15	0	0	5	15	20	0	0	10	40	50
2000	0	0	0	10	10	0	0	5	15	20	0	0	5	20	25	5	5	10	45	55
3000	0	0	5	10	20	0	0	5	15	15	0	0	5	20	30	5	5	10	60	90
4000	0	0	2.5	15	15	0	0	0	15	15	5	5	10	20	35	0	0	10	65	85
6000	0	0	10	25	25	5	5	10	25	30	0	10	15	30	45	0	10	25	65	95
8000	0	0	5	25	40	0	0	5	25	30	0	5	15	35	50	5	5	25	65	95

*Age is grouped in 10yr intervals, that is, ‘30’ represents ages 25 to 34 yrs, etc.

5 dB or more difference with thresholds of the administration group (drillers values higher (worse) than administration)

Underline where administration values are worse than driller values

Table 5-14 Hearing thresholds (in dB HL) for men in the No Noise group (no known occupational noise exposure) for different race and age groups

Hearing-threshold level (dB HL)
Age*
No Noise Group (no known occupational noise exposure)

	30			40			50			60		
	Percentile											
Frequency (Hz)	10	50	90	10	50	90	10	50	90	10	50	90
Black Men	n=791			n=1016			n=693			n=115		
500	0	5	17,5	0	7,5	20	2,5	10	25	5	12,5	35
1000	0	5	15	0	7,5	20	2,5	10	30	5	15	42,5
2000	0	7,5	20	2,5	10	27,5	5	15	40	7.5	22,5	47,5
3000	0	7,5	20	2,5	12,5	32,5	7,5	20	45	10	30	55
4000	2,5	7,5	25	5	15	35	10	25	47,5	15	35	60
6000	5	17,5	32,5	10	22,5	45	15	30	52,5	20	37,5	67,5
8000	5	12,5	32,5	7,5	20	45	12,5	27.5	55	17.5	37,5	67,5
White men	n=554			n=877			n=693			n=243		
500	0	5	15	2,5	7,5	22,5	5	12,5	27,5	3,75	13,7	30
1000	0	5	12,5	0	7,5	20	5	12,5	27,5	5	12,5	46,2
2000	0	5	15	25	10	22,5	5	15	40	8,75	28,7	55
3000	2,5	7.5	20	2,5	12,5	35	10	25	62,5	16,2	50	68,7
4000	2,5	10	25	5	20	47,5	12,5	32,5	65	26,2	50	73,5
6000	5	15	32,5	10	22,5	55	17,5	32,5	65	30	57,5	76
8000	0	12.5	27,5	5	17,5	47,5	15	30	67,5	25	53,7	82,5

*Age is grouped in 10yr intervals, that is, ‘30’ represents ages 25 to 34 yrs, etc.

Table 5-15 Hearing thresholds (in dB HL) for men in Noise Group 1 (underground noise exposure of ≥ 85 dB A) for different race and age groups

Hearing-threshold level (dB HL)
Age*
Noise Group 1(underground occupational noise exposure)

	30			40			50			60		
	Percentile											
Frequency (Hz)	10	50	90	10	50	90	10	50	90	10	50	90
Black Men	n=4133			n=6965			n=5000			n=806		
500	0	5	17,5	0	7,5	20	2,5	10	25	5	15	35
1000	0	5	15	0	7,5	22,5	2,5	10	32,5	5	15	45
2000	0	7,5	17,5	2,5	10	27,5	5	17,5	40	7,5	25	52,5
3000	0	7,5	20	2,5	12,5	35	7,5	22,5	47,5	10	32,5	60
4000	2,5	7,5	22,5	5	17,5	37,5	10	25	50	15	35	62,5
6000	5	17,5	32,5	10	22,5	45	15	30	55	20	40	70
8000	2,5	12,5	30	7,5	20	45	12,5	27,5	57,5	17,5	40	70
White men	n=2367			n=146			n=121			n=30		
500	0	5	15	0	5	15	2,5	10	25	5	12,5	25
1000	0	5	12,5	0	5	17,5	2,5	10	25	5	12,5	30
2000	0	5	15	2,5	7,5	22,5	5	12,5	35	7,5	20	45
3000	0	7,5	22,5	5	15	37,5	7,5	25	57,5	15	37,5	62,5
4000	2,5	10	27,5	5	20	47,5	12,5	32,5	60	22,5	45	67,5
6000	5	15	32,5	7,5	22,5	47,5	17,5	35	65	25	47,5	75
8000	2,5	10	25	5	20	47,5	10	30	65	20	50	80

*Age is grouped in 10yr intervals, that is, ‘30’ represents ages 25 to 34 yrs, etc.
Noise Group 1 values higher (worse) than No Noise values
Underline where No Noise values worse than Noise Group 1 values

Table 5-16 Median threshold values across frequencies for male participants of the No Noise Group and Noise Group 1 categorised by age and compared to ISO 1990:1999 Annex B, as well as Hoffman, Dobie, Ko, Themann, & Murphy (2010)'s proposed new Annex B

A.		Median threshold values of better ear			
MALE		NO NOISE GROUP (Total n:3137)	ISO 1990:1999-Annex B (1990)	Proposed new Annex B (Hoffman, Dobie, Ko, Themann, & Murphy, 2010)	NOISE GROUP 1 (Total n:19402)
Age Group*	Frequency (kHz)				
30 Noise Group 1 (n=4718) No Noise Group (n=953)	0,5	5	7	7	5
	1	5	0	4	5
	2	5	2	4	5
	3	5	9	4	5
	4	5	10	7	5
	6	10	18	11	10
	8	10	---	8	10
40 Noise Group 1 (n=7898) No Noise Group (n=1205)	0,5	5	8	8	5
	1	5	3	6	5
	2	5	4	6	5
	3	10	13	9	10
	4	10	17	13	10
	6	20	24	17	20
	8	15	---	14	15
50 Noise Group 1 (n=5728) No Noise Group (n=829)	0,5	5	10	10	5
	1	5	5	9	5
	2	10	8	10	10
	3	15	19	15	15
	4	20	26	22	20
	6	25	31	25	25
	8	20	---	23	20
60 Noise Group 1 (n=1058) No Noise Group (n=150)	0,5	10	12	11	10
	1	10	6	11	10
	2	20	10	14	20
	3	25	30	25	25
	4	32,5	36	35	30
	6	35	46	40	35
	8	30	----	42	35

*Age is grouped in 10yr intervals, that is, '30' represents ages 25 to 34 yrs, etc.

Table 5-17 Median threshold values across frequencies for female participants of the No Noise Group and Noise Group 1 categorised by age and compared to ISO 1990:1999 Annex B, as well as Hoffman, Dobie, Ko, Themann, & Murphy (2010)'s proposed new Annex B

B.		Median threshold values of better ear			
FEMALE		NO NOISE GROUP (Total n:325)	ISO 1990:1999-Annex B (1990)	Proposed new Annex B (Hoffman, Dobie, Ko, Themann, & Murphy, 2010)	NOISE GROUP 1 (Total n:871)
Age Group*	Frequency (kHz)				
30 Noise Group 1 (n=463) No Noise Group (n=157)	0,5	5	6	7	5
	1	0	1	4	0
	2	0	0	4	5
	3	0	4	2	5
	4	5	4	4	0
	6	5	12	10	10
	8	5	---	7	10
40 Noise Group 1 (n=238) No Noise Group (n=129)	0,5	5	7	7	5
	1	5	2	5	5
	2	5	2	5	5
	3	5	6	4	5
	4	5	6	7	5
	6	10	15	12	10
	8	10	---	10	10
50 Noise Group 1 (n=128) No Noise Group (n=38)	0,5	5	10	10	10
	1	5	4	9	5
	2	10	6	10	5
	3	5	9	15	10
	4	5	9	22	10
	6	15	20	25	15
	8	10	---	23	15
60 Noise Group 1 (n=42) No Noise Group (n=0)	0,5	---	14	11	10
	1		7	11	10
	2		8	14	10
	3		16	25	10
	4		17	35	10
	6		29	40	20
	8		----	42	25

*Age is grouped in 10yr intervals, that is, ‘30’ represents ages 25 to 34 yrs, etc.

Table 5-18 Median threshold values across frequencies for male participants of the administration group (admin) and driller group categorised by age and compared to ISO 1990:1999 Annex B, as well as Hoffman, Dobie, Ko, Themann, & Murphy (2010)'s proposed new Annex B

C.		Median threshold values of better ear			
MALE		ADMIN (Total n: 1124)	ISO 1990:1999-Annex B (1990)	Proposed new Annex B (Hoffman, Dobie, Ko, Themann, & Murphy, 2010)	DRILLER (Total N: 4342)
Age Group *	Frequency (kHz)				
30	0,5	5	7	7	5
ADMIN: n=412	1	5	0	4	5
DRILLER: n=256	2	5	2	4	5
	3	5	9	4	5
	4	5	10	7	5
	6	10	18	11	10
	8	10	---	8	5
40	0,5	5	8	8	5
ADMIN: n=401	1	5	3	6	5
DRILLER: n=1304	2	5	4	6	10
	3	10	13	9	10
	4	10	17	13	15
	6	20	24	17	20
	8	15	---	14	15
50	0,5	10	10	10	10
ADMIN: n=249	1	10	5	9	10
DRILLER: n=2277	2	15	8	10	15
	3	20	19	15	20
	4	20	26	22	20
	6	25	31	25	25
	8	20	---	23	20
60	0,5	10	12	11	15
ADMIN: n=62	1	15	6	11	15
DRILLER: n= 505	2	20	10	14	20
	3	30	30	25	30
	4	35	36	35	30
	6	37,5	46	40	35
	8	40	----	42	35

*Age is grouped in 10yr intervals, that is, ‘30’ represents ages 25 to 34 yrs, etc.

Table 5-19 Median threshold values across frequencies for male participants of the administration group (admin) and driller group categorised by age and compared to ISO 1990:1999 Annex B, as well as Hoffman, Dobie, Ko, Themann, & Murphy (2010)'s proposed new Annex B

D.		Median threshold values of better ear			
FEMALE		ADMIN (Total n: 116)	ISO 1990:1999-Annex B (1990)	Proposed new Annex B (Hoffman, Dobie, Ko, Themann, & Murphy, 2010)	DRILLER (Total n:154)
Age Group*	Frequency (kHz)				
30 ADMIN: n=80 DRILLER: n=46	0,5	5	6	7	5
	1	5	1	4	5
	2	5	0	4	0
	3	5	4	2	5
	4	5	4	4	2,5
	6	10	12	10	10
	8	10	---	7	5
40 ADMIN: n=33 DRILLER: n=38	0,5	5	7	7	7,5
	1	5	2	5	5
	2	5	2	5	5
	3	5	6	4	5
	4	5	6	7	0
	6	10	15	12	10
	8	10	---	10	5
50 ADMIN: n=3 DRILLER: n=53	0,5	5	10	10	10
	1	5	4	9	5
	2	5	6	10	5
	3	5	9	15	5
	4	5	9	22	10
	6	5	20	25	15
	8	15	---	23	15
60 ADMIN: n=0 DRILLER: n=17	0,5	----	14	11	10
	1		7	11	10
	2		8	14	10
	3		16	25	10
	4		17	35	10
	6		29	40	25
	8		----	42	25

*Age is grouped in 10yr intervals, that is, ‘30’ represents ages 25 to 34 yrs, etc.

Table 5-20 Median values for binaural average thresholds across the frequency range for white male participants of Noise Group 1 and the No Noise Group, compared to ANSI S3.44 (1996) Annex C

E.		Median values for hearing threshold dB HL Binaural averages								
MALE, White		No Noise Group (Total n:464)			ANSI S3.44 (1996) Annex C			Noise Group 1 (Total n:2367)		
Age Group *	Frequency (kHz)									
		Percentiles								
		10	50	90	10	50	90	10	50	90
30 No Noise Group: n=554 Noise Group 1: n=146	0,5	0	5	15	3	9	17	0	5	15
	1	0	5	12,5	-1	5	13	0	5	12,5
	2	0	5	15	-4	3	14	0	5	15
	3	2,5	7,5	20	-1	6	27	0	7,5	22,5
	4	2,5	10	25	1	12	37	2,5	10	27,5
	6	5	15	32,5	4	17	43	5	15	32,5
	8	0	12,5	27,5	----	----	----	2,5	10	25
40 No Noise Group: n=877 Noise Group 1: n=167	0,5	2,5	7,5	22,5	4	10	19	0	5	15
	1	0	7.5	20	0	6	17	0	5	17,5
	2	2,5	10	22,5	-1	6	20	2,5	7,5	22,5
	3	2,5	12,5	35	3	12	38	5	15	37,5
	4	5	20	47,5	6	21	50	5	20	47,5
	6	10	22,5	55	10	26	58	7,5	22,5	47,5
	8	5	17,5	47,5	----	----	----	5	20	47,5
50 No Noise Group: n=693 Noise Group 1: n=121	0,5	5	12,5	27,5	5	11	21	2,5	10	25
	1	5	12,5	27,5	1	8	20	2,5	10	25
	2	5	15	40	1	10	29	5	12,5	35
	3	10	25	62,5	6	20	48	7,5	25	57,5
	4	12,5	32,5	65	11	30	58	12,5	32,5	60
	6	17,5	32,5	65	15	36	67	17,5	35	65
	8	15	30	67,5	----	----	----	10	30	65
60 No Noise Group: n=243 Noise Group 1: n=30	0.5	3,75	13,75	30	6	13	24	5	12,5	25
	1	5	12,5	46,25	2	10	24	5	12,5	30
	2	8,75	28,75	55	3	15	41	7,5	20	45
	3	16,25	50	68,75	9	31	56	15	37,5	62,5
	4	26,25	50	73,5	16	41	63	22,5	45	67,5
	6	30	57,5	76	20	47	71	25	47,5	75
	8	25	53,75	82,5	----	----	----	20	50	80

*Age is grouped in 10yr intervals, that is, ‘30’ represents ages 25 to 34 yrs, etc.

Table 5-21 Median values for binaural average thresholds across the frequency range for black male participants of Noise Group 1 and the No Noise Group categorised by age compared to ANSI S3.44 (1996) Annex C

	F.	Median values for hearing threshold dB HL Binaural averages								
MALE, Black		No Noise Group (Total n:2615)			ANSI S3.44 (1996) Annex C			Noise Group 1 (Total n:16904)		
Age Group *	Frequency (kHz)									
		Percentiles								
		10	50	90	10	50	90	10	50	90
30	0,5	0	5	17,5	-1	6	14	0	5	17,5
No Noise Group: n=791 Noise Group 1: n=4133	1	0	5	15	-4	1	7	0	5	15
	2	0	7,5	20	-6	0	5	0	7,5	17,5
	3	0	7,5	20	-5	3	13	0	7,5	20
	4	2,5	7,5	25	-3	3	15	2,5	7,5	22,5
	6	5	17,5	32,5	-4	5	17	5	17,5	32,5
	8	5	12,5	32,5	----	----	----	2,5	12,5	30
40	0,5	0	7,5	20	-2	5	13	0	7,5	20
No Noise Group: n=1016 Noise Group 1: n=6965	1	0	7,5	20	-4	2	9	0	7,5	22,5
	2	2,5	10	27.5	-5	1	8	2,5	10	27,5
	3	2,5	12,5	32.5	-4	5	19	2,5	12,5	35
	4	5	15	35	-3	7	22	5	17,5	37,5
	6	10	22,5	45	-3	9	25	10	22,5	45
	8	7,5	20	45	----	----	----	7,5	20	45
50	0,5	2,5	10	25	5	11	21	2,5	10	25
No Noise Group: n=693 Noise Group 1: n=5000	1	2,5	10	30	1	8	20	2,5	10	32,5
	2	5	15	40	1	10	29	5	17,5	40
	3	7,5	20	45	6	20	48	7,5	22,5	47,5
	4	10	25	47,5	11	30	58	10	25	50
	6	15	30	52,5	15	36	67	15	30	55
	8	12,5	27,5	55	----	----	----	12,5	27,5	57,5
60	0,5	5	12,5	35	6	13	24	5	15	35
No Noise Group: n=115 Noise Group 1: n=806	1	5	15	42,5	2	10	24	5	15	45
	2	7,5	22,5	47,5	3	15	41	7,5	25	52,5
	3	10	30	55	9	31	56	10	32,5	60
	4	15	35	60	16	41	63	15	35	62,5
	6	20	37,5	67,5	20	47	71	20	40	70
	8	17,5	37,5	67,5	----	----	----	17,5	40	70

*Age is grouped in 10yr intervals, that is, ‘30’ represents ages 25 to 34 yrs, etc.

Table 5-22 Median values for binaural average thresholds across the frequency range for black male participants of the driller and administration groups (admin) categorised by age compared to ANSI S3.44 (1996) Annex C

G.		Median values for hearing threshold dB HL Binaural averages								
MALE, Black		Admin			ANSI S3.44 (1996)			Driller		
Age Group *	Frequency (kHz)	(Total n:978)			Annex C			(Total n:2514)		
		Percentiles								
		10	50	90	10	50	90	10	50	90
30 Admin: n=336 Driller: n=54	0,5	0	5	15	-1	6	14	0	6,25	15
	1	0	5	12,5	-4	1	7	0	5	15
	2	0	7,5	20	-6	0	5	0	7,5	20
	3	0	7,5	22,5	-5	3	13	0	7,5	22,5
	4	0	10	25	-3	3	15	0	10	25
	6	5	17,5	35	-4	5	17	2,5	15	32,5
	8	2,5	15	32,5	----	----	----	2,5	11,25	25
40 Admin: n=365 Driller: n=520	0,5	0	7,5	20	-2	5	13	0	10	22,5
	1	0	7,5	20	-4	2	9	0	7,5	27,5
	2	2,5	10	25	-5	1	8	2,5	12,5	32,5
	3	2,5	12,5	32.5	-4	5	19	2,5	5	40
	4	2,5	15	35	-3	7	22	5	20	45
	6	7,5	22,5	50	-3	9	25	10	25	50
	8	2,5	20	42.5	----	----	----	5	22,5	55
50 Admin: n=226 Driller: n=1654	0,5	0	10	27,5	5	11	21	0	12,5	27,5
	1	0	10	35	1	8	20	2,5	12,5	37,5
	2	5	17,5	40	1	10	29	2,5	17,5	52,5
	3	5	25	47,5	6	20	48	5	25	50
	4	10	27,5	52,5	11	30	58	7,5	27,5	52,5
	6	12,5	32,5	55	15	36	67	12,5	32,5	57,5
	8	7,5	30	57,5	----	----	----	7,5	30	57,5
60 Admin: n=51 Driller: n=286	0,5	5	17,5	40	6	13	24	2,5	15	40
	1	2,5	20	45	2	10	24	2,5	20	50
	2	7,5	25	57,5	3	15	41	5	28,75	60
	3	5	32,5	60	9	31	56	7,5	37,5	62,5
	4	12,5	35	65	16	41	63	12,5	40	65
	6	12,5	42,5	70	20	47	71	17,5	43,75	75
	8	10	42,5	70	----	----	----	15	45	75

*Age is grouped in 10yr intervals, that is, ‘30’ represents ages 25 to34 yrs, etc.

Table 5-23 Median values for binaural average thresholds across the frequency range for white male participants of the administration (admin) and driller groups categorised by age compared to ANSI S3.44 (1996) Annex C

H.		Median values for hearing threshold dB HL Binaural averages								
MALE, White		Admin (Total n:124)			ANSI S3.44 (1996) Annex C			Driller (Total n:46)		
Age Group *	Frequency (kHz)									
		Percentiles								
		10	50	90	10	50	90	10	50	90
30	0,5	0	5	15	3	9	17	2,5	12,5	25
Admin: n=69 Driller: n=9	1	0	5	12,5	-1	5	13	0	2,5	12,5
	2	0	5	15	-4	3	14	0	2,5	12,5
	3	0	7,5	20	-1	6	27	0	7,5	25
	4	2,5	10	22,5	1	12	37	0	7,5	20
	6	5	12,5	32,5	4	17	43	2,5	10	27,5
	8	0	12,5	27,5	----	----	----	0	7,5	22,5
40	0,5	1,25	7,5	23,75	4	10	19	2,5	8,75	17,5
Admin: n=30 Driller: n=14	1	1,25	5	23,75	0	6	17	0	6,25	15
	2	2,5	8,75	30	-1	6	20	2,5	8,75	22,5
	3	3,75	12,5	37,5	3	12	38	5	12,5	37,,5
	4	2,5	16,25	47,5	6	21	50	5	23,75	42,5
	6	6,25	17,5	56,25	10	26	58	12,5	28,75	62,5
	8	2,5	13,75	51,25	----	----	----	12,5	20	52,5
50	0,5	5	12,5	32,5	5	11	21	7,5	12,5	35
Admin: n=17 Driller: n=16	1	5	10	35	1	8	20	2,5	6,25	32,5
	2	7,5	15	47,5	1	10	29	5	13,75	32,5
	3	5	27,5	62,5	6	20	48	5	17,5	55
	4	7,5	32,5	65	11	30	58	10	17,5	57,5
	6	17,5	63,75	90	15	36	67	5	30	62,5
	8	20	30	65	----	----	----	10	33,75	70
60	0,5	5	13,75	65	6	13	24	5	25	54,5
Admin: n=8 Driller: n=7	1	5	13,75	52,5	2	10	24	7,5	15	54,5
	2	7,5	25	72,5	3	15	41	2,5	15	62
	3	15	50	75	9	31	56	5	27.5	64,5
	4	20	55	82,5	16	41	63	7,5	32.5	64,5
	6	30	63,75	90	20	47	71	15	52.5	67
	8	27,5	57,5	87,5	----	----	----	12,5	57.5	70

*Age is grouped in 10yr intervals, that is, ‘30’ represents ages 25 to 34 yrs, etc.

5.6. Sub aim 5: To evaluate the effectiveness of the current impairment criteria to identify NIHL and compare it to other existing criteria

In South Africa compensation is based on the definition of hearing impairment as defined in the guideline from the RSA Compensation Commissioner, Instruction 171 (RSA Department of Labour, 2001). Instruction 171 introduced a measure of impairment termed percentage loss of hearing (PLH) which is calculated by using a series of tables based on a summation of hearing loss in each ear at the following frequencies: 500, 1 000, 2 000, 3 000 and 4 000 Hz (RSA department of Labour, 2001). Apart from calculation with Instruction 171, the other methods use a five: one favouring the better ear, and a 25dB HL low fence (Dobie, 2001). One such widely-used method to calculate hearing impairment (most American states use or permit its use) is the AMA (1979) method (Dobie, 1992; AAA, 2003; AMA, 1955). Dobie (2001) discussed in detail evidence that supports the use of the AMA method to appraise the effect of hearing loss in everyday life. The AMA method calculates a percentage hearing impairment as follows: From the pure-tone average (PTA) threshold for 0,5, 1, 2, and 3 kHz (PTA5123), a monaural hearing impairment (MHI) score is calculated: MHI (%)= 1,5 (PTA5123 – 25). The range of MHI is 0 to 100%. When hearing is symmetrical, MHI and the binaural hearing impairment (BHI) are identical, but when there is asymmetry, BHI is a weighted average of the right and left ear MHI scores, favouring the better ear (5:1) (American Medical Association (AMA), 2001).

Using the PLH calculations results were divided into different PLH categories namely PLH 5 (PLH values between 0-5 %), PLH 10 (6-10%), PLH 15 (11-15%), PLH 20 (16-20%), PLH 25 (21-25%), PLH 50 (26-50%), PLH 100 (51-100%). The AMA formula was used to calculate AMA values for each participant. For each of the different PLH categories mean AMA values were calculated and are shown in figure 5.25. The comparison aimed to show whether values of the PLH compared to the AMA are similar or not. If values are similar, the AMA mean should be included in the category values, for example within category PLH 5-10, a similar AMA value would be between 5 and 10 dB. A red circle indicated where these categories did not overlap with the AMA means.

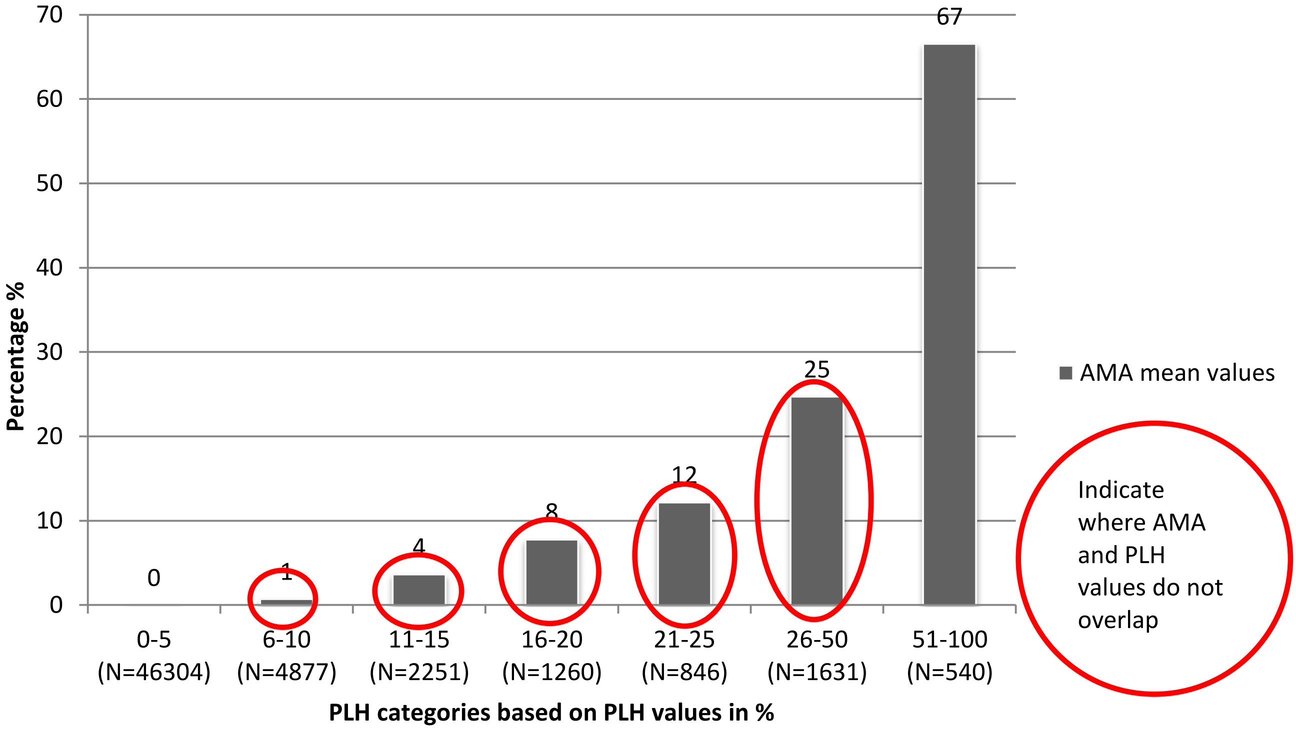
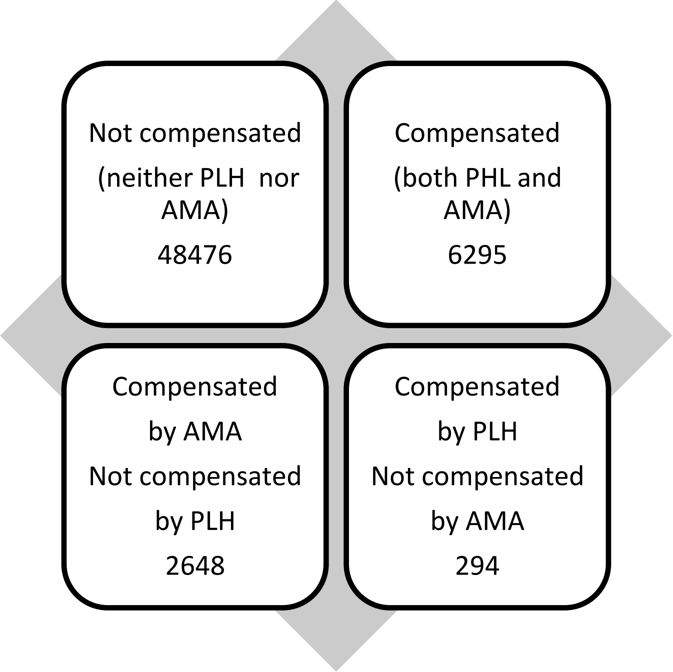


Figure 5-24 Mean values for binaural hearing impairment calculated using the AMA formula for participants in the different PLH groups. PLH groups based on the PLH values in percentage calculated for all participants (N=57691)

From figure 5.24 it appears that the means of the AMA calculations were mostly (with the exception of the PLH 51-100% group) lower than the associated PLH values. For example, in the PLH group with PLH values between 16 and 20% the associated AMA mean was 8%. Only for the PLH group with normal hearing and the most severe hearing impairments (based on PLH values) did the AMA averages overlap with the PLH values. These results were based on AMA values for the specific PLH category. Subsequently AMA values were evaluated independently and compared to PLH values in terms of compensation.

Based on the guidelines from Instruction 171 (COIDA, 2001) a person has a hearing impairment compensable under law when a 10% shift in PLH from baseline is present. The assumption can be made that the lowest PLH indicating compensable hearing impairment is 10%. With the AMA any loss constituting more than 0% hearing impairment is defined as compensable hearing loss.

In order to compare compensable hearing impairment based on the different formulae the minimum required hearing impairment for compensation was calculated. The number of participants in the PLH≥10% and AMA >0% were calculated and compared. Results are shown in figure 5.25.



Not compensated (neither PLH nor AMA) 48476	Compensated (both PHL and AMA) 6295
Compensated by AMA Not compensated by PLH 2648	Compensated by PLH Not compensated by AMA 294

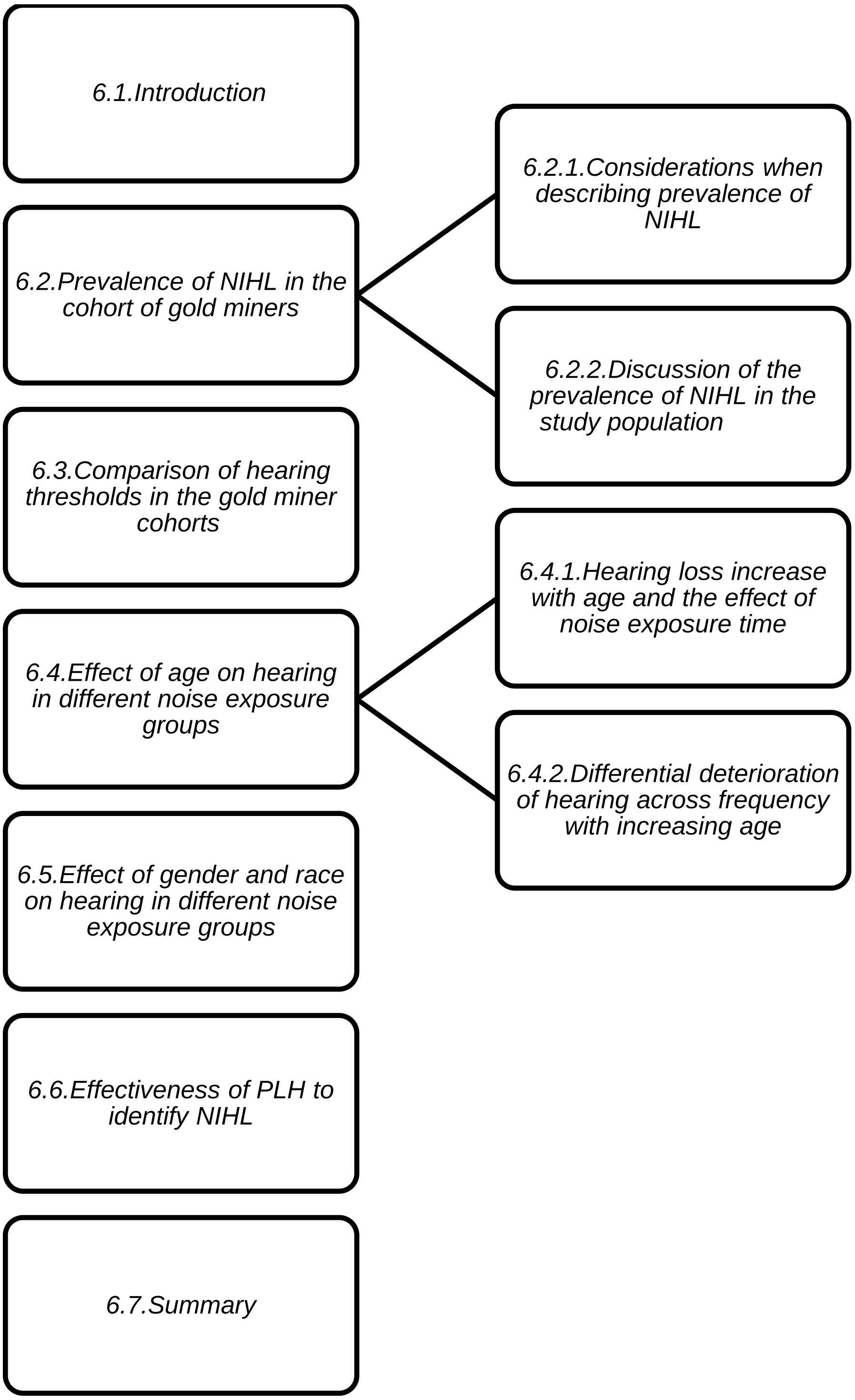
Figure 5-25 Comparison of numbers of participants (total N=57713) who would have been compensated based on the hearing impairment comparing the PLH and AMA formulae of hearing impairment

From figure 5.25 it is clear that the majority of participants in the cohort did not have a compensable hearing impairment. These participants were followed in numbers by participants whose hearing impairment was of sufficient degree to have been compensated if either formula was used. A large number of participants (2 648) revealed a hearing impairment that would have been compensated if the AMA formula but not the PLH formula was used. When using the calculations of the PLH method only 295 participants that did not show a significant hearing impairment (compensable) would have been compensated based on the calculation of the AMA formula.

5.7. Chapter summary

This chapter provided a presentation of the results obtained in the empirical study. This included qualitative data with inferential statistics presented according to the sub aims specified for this study aiming to address the main aim of the study.

6. Discussion



6.1. Introduction

In the previous chapter, chapter 5, the results of this study have been presented according to the sub aims of this study. In this chapter the results will be discussed within the context to existing literature related to the findings of this study. Results will be discussed together according to the subheadings illustrated in figure 6.1 against the sub aims of this study.

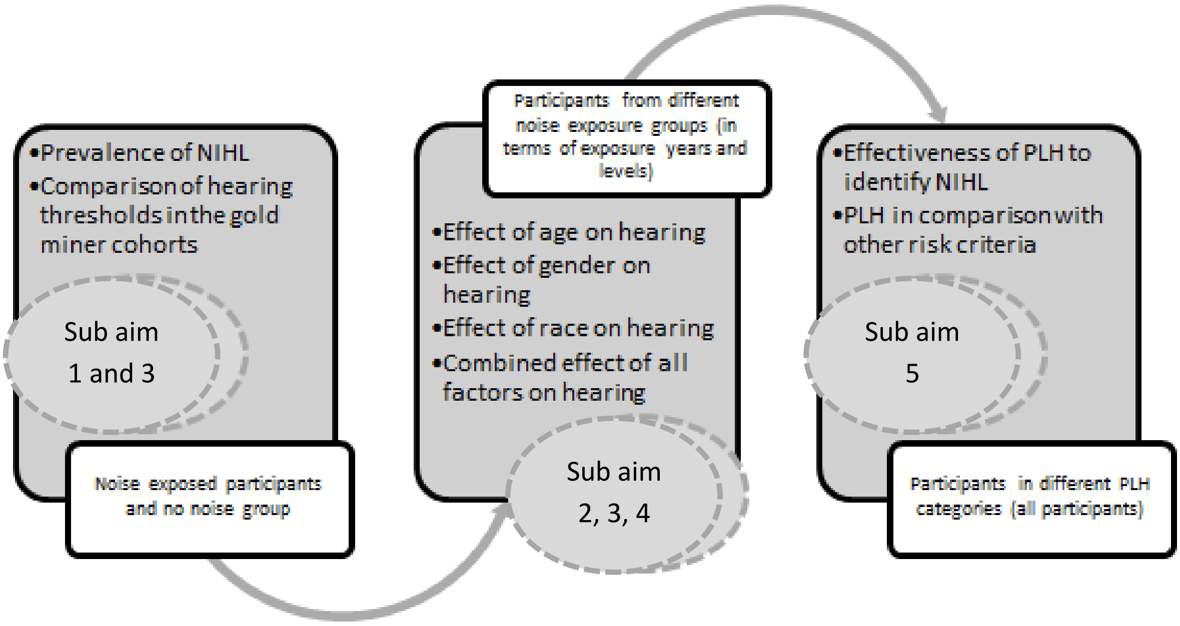


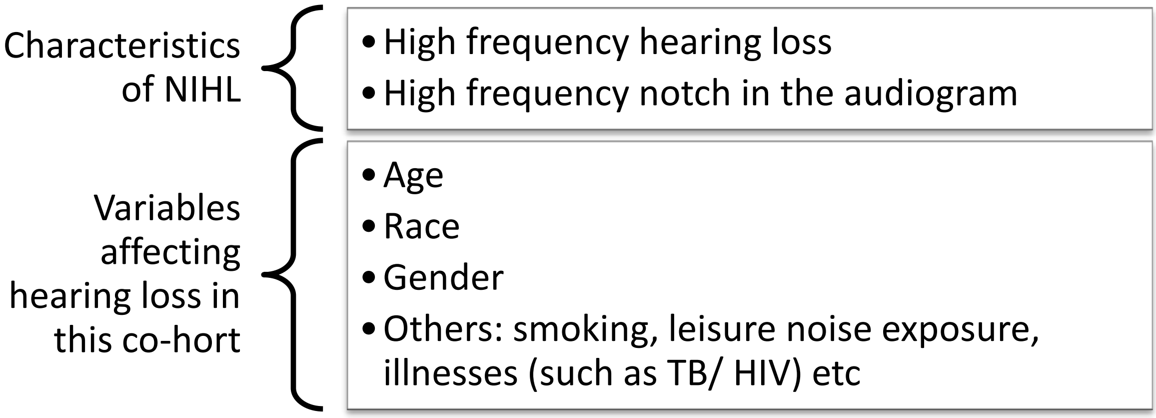
Figure 6-1 Framework for discussion of study findings related to study aims

The following section will highlight important factors that need to be considered when interpreting the results.

6.2. Prevalence of NIHL in the cohort of gold miners

6.2.1. Considerations when describing prevalence of NIHL

The following aspects should be taken into account to answer the question whether a group of gold miners exposed to high levels of occupational noise have a higher prevalence of noise-induced hearing loss: characteristics of NIHL and variables that might have influenced hearing in this cohort.



NIHL is characterised by a high-frequency hearing loss that may display a high-frequency notch in the audiogram (Harding & Bohne, 2007; Le Prell, et al., 2007; McBride & Williams, Audiometric notch as a sign of noise induced hearing loss, 2001; Pyykkö, et al., 2007b; Wilson, 2011). If the cohort of miners displayed hearing loss consistent with these characteristics it would be consistent with the presence of NIHL in this cohort. Several variables influence hearing in workers and these should be considered when identifying NIHL in the population under investigation.

During the discussion, results of this study will be compared to other study populations, population standards and also the unique control group (No Noise group). Published population standards have often been used for comparison purposes in order to describe the prevalence of NIHL in a study population (Agrawal, et al., 2010; Hoffman, Dobie, Ko, Themann, & Murphy, 2010; Dobie, 2008; Nelson, et al., 2005). International as well as American standards (ISO 1990:1999 & ANSI S3.44-1996) describe the distributions of hearing thresholds (10th, 50th, and 90th percentiles, for 0,5 to 6 kHz) associated with age and gender and have been used to estimate the effect of noise on hearing. Different annexes to these standards give threshold distributions for people who never had noisy jobs, occupations with noise levels below 85 dB A (TWA). It is then proposed and utilised as an appropriate comparison standard for study populations with occupational noise exposure. The assumption is that any differences that are found could be attributed to the effect of occupational noise on hearing (Hoffman, Dobie, Ko, Themann, & Murphy, 2010). It has however been shown that people who work in settings with high levels of occupational noise (noisy jobs) were also more likely to smoke, more likely to have non-occupational noise exposure, compared with people who did not have noisy jobs (Agrawal, et al., 2009; Kurmis & Apps, 2007). Thus, differences in threshold distributions between these standards and an occupationally noise-exposed study population could partly be due to any or all these factors. These are factors that have been claimed both to increase the prevalence of hearing loss in the general population, and also to increase susceptibility to NIHL. Thus, their effect could be either to increase or to decrease the relative contribution of occupational noise. For these reasons it has been stated that theoretically, the most appropriate population standard for such comparisons would be one that is similar to the study population in every respect except occupational noise (Hoffman, Dobie, Ko, Themann, & Murphy, 2010).

In order to control these factors that might influence hearing, a control group that was similar in most every respect with reference to their environment and biographical characteristics to the group exposed to occupational noise was selected for comparison. The unique characteristics of the group of South African gold miners were considered and shared between the occupationally noise exposed and the No Noise Group. Comparing these groups paired by the occupational noise levels they were exposed to, made it possible to calculate the prevalence of NIHL in the noise-exposed groups. The influence of age, gender and race was considered and investigated and will be described in the following sections. Other factors unique to this population that might influence results include exposure to leisure noise, smoking and tuberculosis (TB) and human immunodeficiency virus (HIV) (Cheyip, et al., 2007; Ferrite & Santana, 2005; Fransen, et al., 2008; Pouryaghoub, et al., 2007; Wild, et al., 2005; Brits, Strauss, Eloff, Becker, & Swanepoel, 2011; Chandrasekhar, Conelly, Brahrnbhatt, Shah, Kloser, et al., 2000). Pertaining to these factors the following paragraphs will briefly discuss its possible presence in the study cohort.

No information was supplied about smoking habits of participants in this cohort. It has been reported that smoking prevalence in the mining sector differs to that of other sectors (Cheyip, et al., 2007). In a large scale study conducted in a South African platinum mine (N=25 274) it was noted that in 2002 the prevalence of smoking in black mine employees was 12,1% lower than that in black men in the general population (Cheyip, et al., 2007). The Economics of Tobacco Control Project reported an overall prevalence of smoking in the mining sector as 43,5% in 2000 (Cheyip, et al., 2007).

Occupational exposure limits are based on damage risk criteria that assume that non-occupational time is spent at very low noise levels which allow the ear to recover. Data from several studies have shown that it is not always the case (Neitzel, Seixas, Goldman, & Daniell, 2004). High levels of non-occupational noise exposure have also been described in a South African study investigating the noise levels of a unique South African instrument used during soccer games, the vuvuzela (Swanepoel & Hall, 2010). Soccer, or football, is a very popular recreational activity in South Africa and the Vuvuzela is used extensively at these games. Average sound exposure levels during the match were measured at 100,5 dB A (TWA), with peak intensities averaging 140,4 dB C. As a result significant changes in post-match hearing thresholds and cochlear responsiveness were evident for spectators sampled. This is only one example of a popular recreational activity associated with high levels of noise. It is thus important to consider cultural influences on recreational activities when comparing hearing between groups.

TB and its associated risk profile present a complex interaction that may predispose individuals, especially those exposed to occupational noise, to permanent hearing loss (teWaterNaude, et al., 2006; Brits, et al., 2011). It is estimated that the prevalence of TB in South African gold mines could be as high as 3000/ 100 000 (teWaterNaude, et al., 2006). A study of the effect of TB on the hearing status of gold miners was conducted in conjunction with this study (Brits, et al., 2011). The data of the group of gold miners with TB were extracted from the large dataset of this study. The study concluded that a significant relationship between TB and deterioration in hearing thresholds exists. Participants with TB were present in the No Noise Group as well as the Noise Groups. A total of 2 698 miners from the large dataset, N=57714, thus 4,7% were diagnosed with TB. This relatively small percentage of TB-infected workers was represented in all the different noise-exposed groups and the control group.

Finally a high incidence of HIV (human immunodeficiency virus) has been reported in gold mining (an estimated 30%) (Chamber of Mines, 2012). HIV has been described as significant health risks in South African mining because this disease is associated with the living and working conditions of miners, such as migrant labour, single gender hostels and dense living arrangements (Hermanus, 2007). HIV could thus be present in the noise as well as control groups. Hearing loss has been described as a possible symptom of HIV patients (Chandrasekhar, et al., 2000; Bankaitis & Keith, 1995; Singh, et al., 2003; Sonnenberg, et al., 2005).

In the previous paragraphs factors that might influence hearing in the cohort were highlighted. These factors were present in both the control and noise-exposed groups. When comparing noise-exposed groups to published standards these factors might also be present, yet in the unique control group these factors were more effectively controlled. This section noted factors and aspects that should be considered when describing the prevalence of NIHL in a population. In the following section prevalence of NIHL in this cohort will be discussed.

6.2.2. Discussion of the prevalence of NIHL in the study population

The current study found that exposure to occupational noise was significantly associated with increased hearing thresholds as was shown in other international reports (Agrawal, et al., 2010; Amedofu, 2002; Dobie, 2008; Nelson, et al., 2005; Nelson, et al., 2005a; Scott, et al., 2004; Uddin, et al., 2006). Significantly more participants in the noise groups presented with all degrees of hearing loss (HFA346 as well as LFA512) than participants in the group with no known occupational noise exposure.

Noise Groups were defined for comparisons with the control group. The following figure 6.2 summarises these groups and their prevalence results.

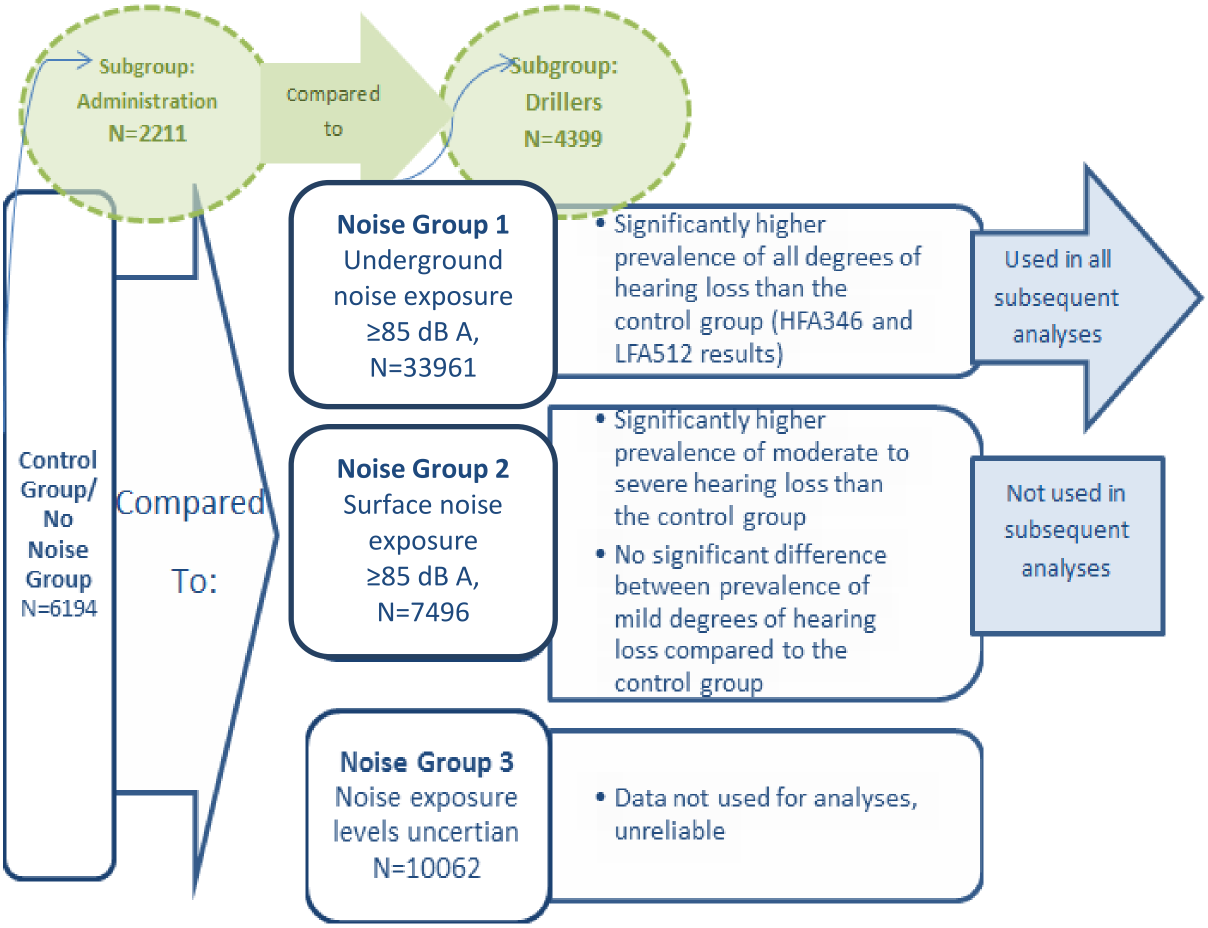


Figure 6-2 Different noise groups, and sub groups, the prevalence of NIHL compared to the control group and data used in analyses

As the prevalence data showed variable significance between the prevalence of NIHL in Noise Group 2 and the control group, subsequent analyses (frequency specific) were done of the data from Noise Group 1. Underground noise sources, such as blasting and drilling underground, differ from that on the surface, being influenced by mine geometry, openings and friction from wall roughness. As with other impulsive exposures, the cumulative effect on mine workers is unclear (McBride, 2004). Analyses were also done of data from two sub groups of Noise Group 1 and the control groups which are described as homogeneous exposure groups (HEGs). These two groups were the Driller and Administrative groups. Results of these analyses will also be incorporated in this discussion. Noise Group 1, which included participants from occupations exposed to high levels of underground noise, revealed a significantly smaller proportion of workers with normal hearing than the proportion of workers in the group not exposed to occupational noise.

Although there was a statistically significant difference in proportions of participants with hearing loss between the noise exposed and the control group within the different hearing sensitivity categories, high-frequency hearing loss was also present in the control group. For example, 16% of the control group participants had a hearing loss greater than 30 dB HL compared to the 20% of Noise Group 1. The relative small difference between the two groups is evidence that hearing conservation programmes are largely effective. The slightly higher prevalence of high-frequency hearing loss in the noise-exposed group, compared to the control group, however, suggests that a proportion of workers still do acquire noise-induced hearing loss.

Apart from the normal effect of aging on hearing, the control group may have included persons with some previous exposure to occupational noise since information on the previous work history of participants was not available. According to the occupational health manager at the participating mines this possibility is unlikely since advancement from noisy jobs to administrative jobs is not typical in the mine (personal communication, Eloff, 2009). Exposure to noise sources other than occupational noise might also be considered in the control group. High levels of non-occupational noise exposure was described in a South African study investigating the noise levels of a unique South African instrument used during soccer games, the vuvuzela (Swanepoel & Hall, 2010) for instance. It is thus possible that non-occupational noise exposure could exacerbate or cause NIHL in occupationally exposed and unexposed participants. The exposure of mine workers to leisure noise should be investigated further. The high incidence of HIV (human immunodeficiency virus) reported in gold mining (an estimated 30%) (Chamber of Mines, 2012) might be partly attributing to hearing loss in the noise and control groups. In a recent study a significant degree of high-frequency sensorineural hearing loss was observed in HIV patients (Chandrasekhar, et al., 2000).

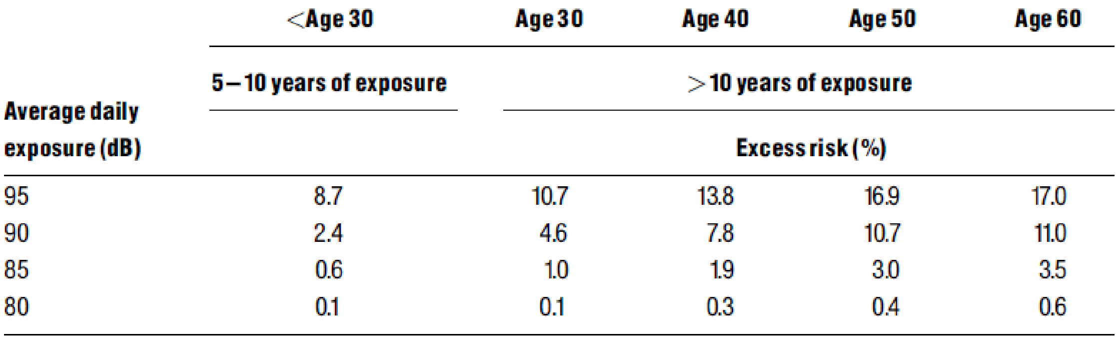
Comparisons of prevalence findings in the present study with those from other published papers are difficult because of the lack of agreement on a standard definition of hearing loss, differences in age, gender and race in the populations tested and differences in the test frequencies. When comparing prevalence data from other international studies to the data of this study, several variables should be taken into account. These include: the metrics or formula used when defining hearing loss, the determined level where hearing loss begin, the level of noise exposure and the population with its unique characteristics. Only a few large-scale prevalence studies have been published. Some studies collected data from several studies and inferred prevalence of NIHL from these results.

One such a study is that of Nelson and colleagues conducted as part of the WHO Global Burden of Disease project (Nelson, et al., 2005a). This study utilised estimates of the proportion of the population exposed to a risk factor, the approximate level(s) of that exposure, and the resulting relative risk(s) of that exposure, for 14 WHO epidemiological subregions, both genders, and seven age groups. During this study the authors employed the data of international studies to estimate the burden of NIHL globally. The studies used to infer the fraction of people with NIHL in developing countries was mostly small-scale studies with sample sizes smaller than 2 667, which was the largest study sample for which data were available (Nelson, et al., 2005a; Hessel & Sluis-Cremer, 1987).

Pure tone averages (PTA) for 1, 2, 3, and 4 kHz (NIOSH, 1998) were used as the metric for excess risk for levels up to 90 dB A (Nelson, et al., 2005a). Age weighting was also included in their model. It was estimated that NIHL accounted for 18% of hearing loss in the Africa region of which the RSA is a part. The suggested burden of NIHL in the RSA, based on the Nelson study estimates (with hearing loss greater than 40 dB HL), could be approximately 18%. The Nelson estimates of the United States of America is less than 10% and although the study methodology has been criticised (for example, different hearing loss definitions were used for age-related hearing loss (ARHL) and NIHL, and relative risk estimates from American data were grafted onto British data) it correlates with prevalence estimates from a study by Dobie (Dobie, 2008). In this study the author used data from an international standard that predicts age-related and noise-induced hearing loss (ISO, 1990), the American Medical Association method of determining hearing impairment (PTA5123), and from sources estimating the distribution of occupational noise exposure in different age and gender groups to construct a model for NIHL burden in American adults. Although the methodology differs from the Nelson et al. (2005)

study, the fraction of people with occupational NIHL more than 40 dB HL in North America was estimated at 10,5% (similar to the Nelson estimate of 8,5%) (Dobie, 2008).

Hearing loss for the Nelson and colleagues study (2005) was defined as 41 dB HL and more. Risk[21] estimates were defined for different levels of noise exposure. This was defined as the percentage of the workers with a hearing impairment in an occupationally noise-exposed population after subtracting the percentage who would normally incur such impairment from aging in an unexposed population (Nelson, et al., 2005a). These percentages of occupationally exposed people at risk for hearing loss greater than 41 dB HL are shown in figure 6.3.



Average daily exposure (dB)	<Age 30	Age 30	Age 40	Age 50	Age 60
	5–10 years of exposure	>10 years of exposure			
		Excess risk (%)			
95	8.7	10.7	13.8	16.9	17.0
90	2.4	4.6	7.8	10.7	11.0
85	0.6	1.0	1.9	3.0	3.5
80	0.1	0.1	0.3	0.4	0.6

Figure 6-3 Estimated excess risk for hearing impairment at 41dB HL or greater, by age and duration of the exposure (Source: Nelson, et al., 2005)

When looking at the prevalence of hearing loss in the current study population, a high-frequency average (HFA346) and a low-frequency average (LFA512) were used. Hearing loss was graded between 16 dB HL and approximately 60 dB HL at the most as a classification growing at a faster pace was preferred to aid early identification of NIHL (Picard, 2012; Yantis, 1994). Of the participants in Noise Group1 (exposed to underground noise of more than 85 dB A), approximately 11,2% showed a hearing loss greater than 40 dB HL. Of the participants in the No Noise Group 8% revealed a hearing loss greater than 40 dB HL when the HFA346 was used. Because of the high-frequency characteristics of NIHL the HFA346 is more

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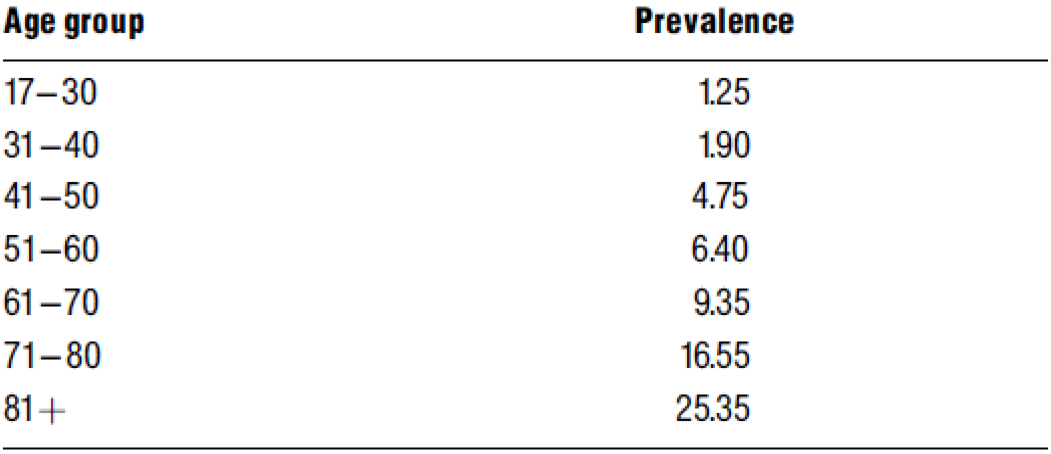
[21] Percentage of the workers with a hearing impairment in an occupationally noise-exposed population after subtracting the percentage which would normally incur in such impairment from aging in an unexposed population. (Nelson, et al., 2005a).

likely to be indicative of NIHL than the LFA512. When the low frequencies were used as an average (LFA512) only 2,8% of the participants in Noise Group1 had a hearing loss greater than 40 dB HL compared to the even smaller proportion of the participants in the No Noise Group (1,6%). When using the Nelson et al. (Nelson, et al., 2005a) level for hearing loss (≥41dB HL) prevalence values for this study, based on HFA346 results when divided into different age categories, show that 4,45% of participants in the age group 25 to 34years display a hearing loss of more than 40 dB HL. For the age group 35 to 44 years this percentage was 17%, for the age group 45 to 54 years 39,29% of workers, and this value was 59,7% for the 55 to 64 years group. For the current study however, age weighting has not been done. For the Nelson et al. (2005) study prevalence data of hearing loss in the general population in Great Britain were used (Davis, 1989) to establish the hearing loss expected for different ages. For ease of reference this table is included in figure 6.4.



Age group	Prevalence
17–30	1.25
31–40	1.90
41–50	4.75
51–60	6.40
61–70	9.35
71–80	16.55
81+	25.35

Figure 6-4 Prevalence data of hearing loss greater than 40 dB HL for the general population in Great Britain (Source (Nelson, et al., 2005a; Davis A. C., 1989)

In order to compare Nelson et al. (2005) risk estimates with prevalence values of the population under investigation the following calculations were done: the percentage of people in the age group who would have a hearing loss without the presence of occupational noise (according to Davis 1989) was subtracted from the percentage of participants in each age group with hearing loss more than 40 dB HL minus. The reserve percentages could then be compared to the Nelson et al. (2005) risk estimates. For all the age groups this study's prevalence across different age groups was higher than those of the Nelson et al. (2005) risk estimates (figure 6.2). These differences were: 2,55% (25 to 34years), 12,25% (35 to 44 years), 32,89% (45 to 54 years), and 50,35% (55 to 64 years). These percentages were considerably higher than the risks predicted for noise levels above 95 dB A in figure 6.2 as per Nelson and colleagues (2005). When using the prevalence values for the different age groups of the No Noise Group and subtracting that from those of Noise Group 1 the differences were the following: 0,15% (25 to 34years), 3% (35 to 44 years), 2% (45 to 54 years), and 3% (55 to 64 years). All these differences, except for the age group 35 to 44 years, are comparable with Nelson et al. (2005) risk estimates (figure 6.2) for occupational noise exposure of 85 dB A. For that age group the prevalence of NIHL in Noise Group 1 exceeds the risk predicted.

The fact that developing countries have a heavier burden of NIHL due to occupational noise is supported by the fact that developing countries have younger populations and lesser life expectancy, and thus less age-related hearing loss, and also because of the fact that developing countries often have a decline in manufacturing occupations compared to a raise of these in developing countries (Dobie, 2008). The trend for developing countries to show a rise in manufacturing jobs is emphasised by statistics showing that workers in many developing Asian countries are moving from agriculture to the manufacturing industry (Fuente & Hickson, 2011). Many companies from developed countries have moved their manufacturing plants to these countries due to cheaper labour, yet with good access to technology (Fuente & Hickson, 2011). Because of the lack of specific legislation regarding noise emissions (in developing countries in Asia according to authors Fuente & Hickson (2011)) these emissions are rarely controlled and an increase in NIHL is expected. In a study to evaluate risk of the NIHL several Asian studies on noise and NIHL have been discussed and evaluated (Fuente & Hickson, 2011). As with the Nelson summary of data, several factors complicate comparison between these studies. In the methodology utilised regarding noise measurements differed markedly, with variations in measurement units and exposure times. Regarding the definitions/ metrics of hearing loss used in these studies variation exist between the studies, with some studies considering NIHL as the average of high-frequency thresholds, others as the average of speech frequencies, and others as an audiometric notch configuration at a high frequency. No studies reported on NIHL in mining. One reported study conducted in Taiwan (Wu, Liou, Shen, Hsu, & Chao,

1998) investigated nearly 10 000 workers exposed to noise levels above 85 dB A from different sectors. They found that 34% of workers had hearing thresholds at 4000 Hz higher than 40 dB HL in either one or both ears. Another Taiwanese study found a 57% prevalence of NIHL, defined as hearing levels above 25 dB HL for the average of 500, 1000, and 2000 Hz, among workers exposed to a mean equivalent sound level of 79 dB A (Chang & Chang, 2009). In the current study LFA512 results yield a prevalence of 23,3% for hearing loss greater than 15 dB HL in the noise-exposed group (Noise Group1). From these results it is clear that the prevalence of NIHL in the current population was lower than expected of other developing countries. South Africa is however a low to middle income country with better development than most of the developing world (World Health Organisation, 2012), and hearing conservation is mandated (Department of Minerals and Energy, 1996).

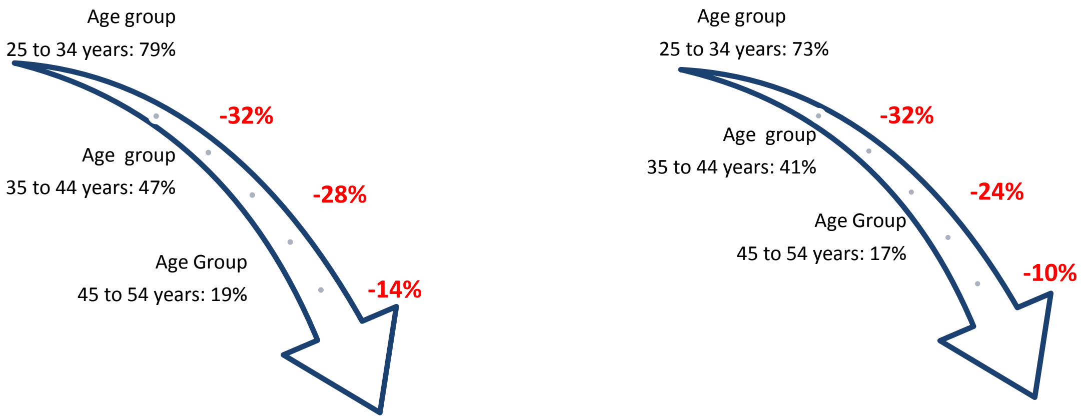
A very large scale study was conducted to investigate any relationship between noise-exposure levels in the workplace, degree of hearing loss (HL), and the relative risk of accident (Girard, et al., 2009; Picard, et al., 2008). This retrospective study of 52 982 male workers aged 16–64 years employed ‘‘hearing status’’ and ‘‘noise exposure’’ from the registry held by the Quebec National Institute of Public Health. Although this was not the aim of this study, prevalence data of hearing loss in these occupationally noise-exposed participants were published in the different age and hearing loss groups. Prevalence data from the population under investigation can be compared with the data published in these studies (total sample size of the Girard et al. (2009) study was 44 400 without the participants in the 16 to 24 years age group). The following table 6.1 aids comparison between the prevalence data of the Quebec study (Girard, et al., 2009) and this study.

Table 6-1 Prevalence data from the current study compared to data from the Girard et al. (2009) study, categorised into ISO (1990) age categories and Yantis (1994) hearing loss categories, HFA346 used to define hearing loss.

Category of hearing sensitivity (dB)* Age group (ISO, 1990)	Participants from the current study (Noise Group1)		Participants from the Girard et al.(2009) study	
Bilateral HFA346 (3, 4, 6 kHz)	Total N=31105		Total N=44400	
Age 25 to 35 years	N=8934	100%	N=18991	100%
Normal hearing 0-15 dB	6557	73,39%	15992	78,94%
Just noticeable HL 16 to 30 dB	1978	22,14%	2824	14,87%
Mild HL 31 to 40 dB	226	2,52%	667	3,51%
Moderate HL 41 to 50 dB	112	1,25%	309	1,63%
Severe HL 51+dB	61	0,68%	199	1,05%
Age 36 to 45 years	N=12303	100%	N=13799	100%
Normal hearing 0-15 dB	4998	40,62%	6531	47,33%
Just noticeable HL 16 to 30 dB	5100	41,45%	4060	29,42%
Mild HL 31 to 40 dB	1189	9,66%	1536	11,13%
Moderate HL 41 to 50 dB	516	4,19%	948	6,87%
Severe HL 51+dB	500	4,06%	724	5,25%
Age 46 to 54 years	N=8087	100%	N=8000	100%
Normal hearing 0-15 dB	1415	17,49%	1550	19,38%
Just noticeable HL 16 to 30 dB	3493	43,19%	2496	31,2%
Mild HL 31 to 40 dB	1378	17,03%	1320	16,5%
Moderate HL 41 to 50 dB	884	10,93%	1176	14,7%
Severe HL 51+dB	917	11,33%	1458	18,25%
Age 56 to 65 years	N=1781	100%	N=3610	100%
Normal hearing 0-15 dB	131	7,35%	179	4,96%
Just noticeable HL 16 to 30 dB	533	29,92%	809	22,41%
Mild HL 31 to 40 dB	320	17,96%	612	16,95%
Moderate HL 41 to 50 dB	295	16,56%	603	16,7%
Severe HL 51+dB	502	28,18%	1407	38,98%

*hearing loss (HL)

A comparison between the data of this study and the Girard et al. (2009) study shows that the current study had a lower prevalence of hearing loss greater than 30 dB HL in all age categories than the Girard et al. (2009) participants. For hearing loss more than 30 dB HL in the age group 25 to 35 prevalence was 4,45% for this study and 6,19% for the Girard et al. (2009) study. Age group 36 to 45 years showed 17,91% prevalence compared to 23,43%, for age group 46 to 54 years prevalence was 39,29% compared to 49,45% and for the age group 56 to 65 years prevalence was 62,7% compared to 69,63%.This difference in prevalence values might be explained by the fact that the Girard et al. (2009) participants were mostly white men, compared to the current study where 85% of participants in Noise Group 1 were black men. Results from this study as well as previous studies have shown that black persons exposed to occupational noise might have better hearing in the high frequencies, suggesting differences in susceptibility to NIHL (Agrawal, et al., 2009; Ishii & Talbott, 1998; Cooper, 1994).The effect of race on current study results will be discussed in section 6.5. For both the Girard et al. (2009) and the current study the percentage of participants in the normal hearing categories declined non-linearly as age increased. The following graph, figure 6.5, demonstrates the negative growth pattern. Negative growth values were calculated by subtracting the difference between prevalence in the younger age group from the older age group.



Girard et al. (2009) prevalence data

Current study prevalence data; Noise Group1

Figure 6-5 Comparison between Girard et al. (2009) and the current study's negative growth in prevalence of the normal hearing category with increase in age (shown as a difference in the percentage of participants with normal hearing between the subsequent age groups)

Both these large datasets show a decline in prevalence of normal hearing in occupationally noise-exposed participants with age that was non-linear. This tendency will be further explored and discussed in section 6.4, where the effect of age on the results will be explored. As can be seen from this data prevalence of hearing loss was greatly affected by age. According to Nelson and colleagues (2005) the fraction of hearing loss that can be attributed to occupational noise decreases as a person grows older (26% of hearing loss in 30 to 44 year olds can be attributable to occupational noise, yet only 3% of 70 to 79 year olds' hearing loss) in the AFR-E region.

Only one survey describing the hearing loss in a group of South African gold miners has been published (Hessel & Sluis-Cremer, 1987). A large cross-sectional survey of hearing loss (N=2667) was conducted in a South African gold mine population (Hessel & Sluis-Cremer, 1987). The results of this study have been reported by numerous other publications (McBride, 2004; Nelson, et al., 2005; Nelson, et al., 2005a; Kurmis & Apps, 2007; Viljoen, Nie, & Guest, 2006). Hearing loss was defined as a low-frequency pure-tone average (0,5, 1, 2 kHz) of 25 dB HL or more. The investigators noted that HPDs were not generally used and if they were worn they were only used part time. None of the miners younger than 22 years old had hearing impairment, rising progressively to 22% of those 58 years old. The participants' ages were grouped in 4-year categories (e.g. 22 to 25 years) for the Hessel and Sluis-Cremer (1987) study, compared to the 10-year categories used in the current study. To calculate the binaural average of the frequencies 0,5, 1 and 2 kHz, Hessel and Sluis-Cremer (1987) used a 5:1 weighting for the better ear (that is 5 times the values for the better ear plus the worst ear PTA divided by 6). For the current study the LFA512 was also calculated, but the binaural value was derived by averaging the left and right ear. As NIHL is typically a symmetrical hearing loss results could still be compared and should not be too variable. To aid comparison table 6.2 summarises the results of the prevalences for LFA512 results for Noise Group 1 and the Hessel and Sluis-Cremer age groups (combined) and prevalences for hearing loss greater than 25 dB HL (PTA512).

Table 6-2 Noise Group 1: Number and percentage of participants in each age group (ISO 1990) for each hearing loss category (Yantis, 1994), combined percentages for hearing loss greater than 30 dB HL and percentage values of Hessel & Sluis-Cremer (1987) participants with PTA512 values greater than 25 dB HL

Category of hearing sensitivity (dB)* Age group (ISO, 1990)	Participants from the current study (Noise Group1)			PTA values for the Hessel & Sluis-Cremer (1987) study
Bilateral LFA512 (0.5,1, 2 kHz)	Total N=31105			Total N=183
Age 25-35 years	8934	100%		Age 22-33 years
Normal hearing 0-15 dB	8137	91		2,8-3,1 % hearing loss ≥ 25 dB HL
Just noticeable HL 16 to 30 dB	657	7,35		
Mild HL 31 to 40 dB	79	0,88	1,55% hearing loss > 30 dB HL	
Moderate HL 41 to 50 dB	29	0,32		
Severe HL 51+dB	32	0,35		
Age 36-45 years	12303	100%		Age 34-45 years
Normal hearing 0-15 dB	9623	78,21		2,7- 6,0 % hearing loss ≥ 25 dB HL
Just noticeable HL 16 to 30 dB	2092	17		
Mild HL 31 to 40 dB	333	2,7	4,76% hearing loss > 30 dB HL	
Moderate HL 41 to 50 dB	113	0,91		
Severe HL 51+dB	142	1,15		
Age 46-54 years	8087	100%		Age 46-53 years
Normal hearing 0-15 dB	4916	60,78		10,7- 10,9 % hearing loss ≥ 25 dB HL
Just noticeable HL 16 to 30 dB	2225	27,51		
Mild HL 31 to 40 dB	560	6,92	11,69% hearing loss > 30 dB HL	
Moderate HL 41 to 50 dB	204	2,52		
Severe HL 51+dB	182	2,25		
Age 56-65 years	1781	100%		Age 54+ years
Normal hearing 0-15 dB	759	42,61		15,7-21,6 % hearing loss ≥ 25 dB HL
Just noticeable HL 16 to 30 dB	600	33,68		
Mild HL 31 to 40 dB	208	11.67	23.32% hearing loss > 30 dB HL	
Moderate HL 41 to 50 dB	108	6,06		
Severe HL 51+dB	106	5,95		

From table 6-2 it is apparent that percentages when combined (as in table 6.2) show a higher prevalence for the two groups in the two youngest age categories for the Hessel & Sluis-Cremer (1987) study. This phenomenon was reversed for the two older age categories with the prevalence of hearing loss for the current study slightly higher. However, for the current study hearing loss greater than 30 dB HL was taken into account and not >25 dB HL for the Hessel & Sluis-Cremer (1987) study. Percentages for all age groups would be higher if the hearing loss category included hearing losses between 25 and 30 dB HL for the current study. It can thus be assumed that prevalence values for the two younger groups could be closed. Even with a definition of hearing loss that excluded losses between 25 and 30 dB HL the current study prevalence values were higher in the older age groups. Because HPD use should be higher in most recent years these results are unexpected. However, several factors should be considered when interpreting these findings. High frequencies were not considered for the PTA (0,5, 1 and 2 kHz) as used in the Hessel and Sluis-Cremer (1987) study and for this comparison.

As NIHL is essentially a high-frequency hearing loss it is possible that hearing loss at present is not due to noise. For the Hessel and Sluis-Cremer study (1987) only white miners’ hearing was considered. The majority of participants in the current study were black miners. As will be shown in section 6.5 when the differences between the results across different races will be considered, white miners tend to have better low-frequency hearing than black miners and the contrary was observed for high frequencies. It has been noted in the introduction to this section that NIHL is typically a high-frequency hearing loss. As these results show results for low and mid frequencies it is possible that other causes of hearing loss should be considered when interpreting these findings. The incidence of TB in South Africa has increased since 1987 when the study of Hessel & Sluis-Cremer (1987) was published. The high prevalence of HIV in the mine workers further increases the risk of contracting TB due to immune suppression (Sonnenberg, et al., 2005). Recent TB reports based on case findings indicate that between 85% and 90% of current TB cohorts were also infected with HIV (AngloGoldAshanti, 2007; World Health Organization, 2009) and because of the effect on the middle ear system low frequencies tend to be more affected.

In this section the prevalence of hearing loss, defined in a number of different ways, was discussed in the light of other publications and results. In the following section the degree of hearing loss across the different frequencies will be highlighted.

6.3. Comparison of hearing thresholds in the gold miner cohorts

For the analysis of data between the occupationally noise-exposed group (Noise Group1) and the control group (No Noise group) sample sizes were large; 33 961 participants in Noise Group 1 and 6 194 participants in the control group. It is important to note that although some observed differences were statistically significant, they may not be clinically relevant. These statistical differences were mainly attributed to the very large sample size resulting in very small standard errors, where $t = \frac{x1-x2}{\sqrt{\frac{SD1}{n1}+\frac{SD2}{n2}}}$. (Large t-values result in very small p-values).

Results of this study have shown that the median values of thresholds across frequencies for the left and right ears were identical for Noise Group 1. Except for 95th percentile values for the No Noise group at 3000 Hz, where left ear threshold values were 5 dB more elevated than for the right ear, no other differences were observed between the different ears. It has been reported that left ears yield worst threshold results than right ears in non-occupationally noise-exposed individuals (Cooper, Ear and race effects in hearing.Health and Nutrition Examination Survey of 1971-75: Part I, 1994; Ciletti & Flamme, 2008; Johansson, Arlinger, & D, 2002). The tendency for worst left ear results has also been shown to be prevalent in persons exposed to occupational noise, especially impulse noise (Raynal, Kossowski, & Job, 2006; Nondahl, Cruickshanks, Wiley, Klein, & Klein, 2000; Rabinowitz, et al., 2006; Śliwińska-Kowlaska, et al., 2006; Wilson, 2011). One explanation might be that right-handed individuals (the majority of the population) will have more direct noise exposure in the left ear from the rifle or machine held in the right hand (Wilson, 2011). However, it has also been reported in some studies that the left ear was tested before the right ear, a methodological practice that might yield better right ear results after conditioning to the test procedure (Henselman, et al., 1995; Margolis & Saly, 2007). In the studies referenced above, reporting worst thresholds for the left ears, it was not noted which ear was tested first.

Comparison between HFA346 and LFA512 results revealed that hearing thresholds in the high frequencies were more elevated in both groups compared to the low frequencies. This was true for median as well as 95th percentile values. Low frequency average medians were identical for the participants of Noise Group1 compared to LFA512 medians for participants in the No Noise group (8 dB). Noise group1 showed worse HFA346 results than those of the No Noise Group. This confirmed the existence of NIHL as NIHL is typically a high-frequency hearing loss (Śliwinska-Kowalska et al., 2006; McBride & Williams, 2001 & Rabinowitz et al., 2006). For 95th percentile results LFA512 and HFA246 values were worse for Noise Group1.

Comparison between the thresholds of the No Noise Group and Noise Group 1 showed median values for these two groups were the same except at 8 kHz where Noise Group 1 showed thresholds 5 dB worse. The largest differences between results for these two groups were for the 95th percentile values across the frequency range. A difference of 5 dB (worse for participants of Noise Group1) at frequencies 1, 2, 4, and 8 kHz were observed. At 3 kHz, thresholds at the 95th percentile were 10 dB worse for participants of Noise Group 1 compared to those for participants of the No Noise group. It is, however, impossible to interpret these results without taking into account the age of participants in the different groups. Because of the many similarities and interactions between NIHL and age-related hearing loss (ARHL) it is imperative to take into account the contribution of ARHL when determining the effect of noise on hearing (Ciletti & Flamme, 2008; Niskar, et al., 2001; Pyykkö, et al., 2007; Dobie, 2001); Hoffman, et al., 2010; Flamme, et al., 2011). In these groups, for instance, 26% of participants in the No Noise group were under the age of 30 years compared to 13% in Noise Group 1. To further explore and understand these differences in thresholds as well as HFA346 and LFA512 results the effect of age, race and gender will be discussed in section 6.5.

Finally, considering the thresholds of the large cohort it was observed, using the notch criteria of Coles, Lutmann and Buffin (2000)[22], a notch was observed at 6 kHz

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[22] Notch criteria of Coles and colleagues (Coles, Lutman, & Buffin, 2000): A high-frequency notch is present where the hearing threshold at 3, 4, and/or 6 kHz is at least 10 dB greater than at 1or 2 kHz and at least 10 dB greater than at 6 or 8 kHz.

(a 15dB notch) in both the noise-exposed and No Noise Groups. Although audiometric high-frequency notches have been described as an indicator of NIHL (McBride & Williams, 2001; Sataloff & Sataloff, 2006; Rabinowitz, et al., 2006; Niskar, et al., 2001; Osei-Lah & Yeoh, 2010) interpretation of the 6 kHz notch has been controversial. More than three decades ago researchers observed the notch at 6 kHz and concluded that the earliest change in hearing due to excessive noise exposure might be found at this frequency (Axelsson, 1979; Salmivalli, 1979).

In a recent survey of the non-institutionalised population of the United States, the National Health and Nutrition Examination Survey (NHANES), data were collected from 2 819 women and 2 525 men between 1999 and 2004 (Ciletti & Flamme, 2008; Hoffman, Dobie, Ko, Themann, & Murphy, 2010). Results from this survey revealed a small notch at 6 kHz for both men and women at younger ages (25 to 34 and 35 to 44 yrs). This notch was observed at the lower and upper percentiles. The observed 6 kHz notch in the NHANES data was attributed to an error in the reference value for audiometric zero when calibrating TDH-39 headphones on an NBS-9A (6 cm3) acoustic coupler (Hoffman, Dobie, Ko, Themann, & Murphy, 2010; Lawton, 2005). Another study by Lutman and Davis (1994) evaluated the hearing of young adults in the United Kingdom during a large random survey (Lutman & Davis, 1994). The researchers also raised concerns about the 6 kHz calibration bias after having found that the younger subjects (screened and unscreened) had unusually increased thresholds at this frequency. Rabinowitz and colleagues (2006) further warned that because of distortion at 6 kHz, an adjustment would be necessary if certain earphone types were used (Rabinowitz, et al., 2006). The headphones used for the collection of data for the current study also were the TDH-39 headphones and this could account for or contribute to the notch observed in the cohort of miners at 6 kHz.

Another explanation for the notch at 6 kHz provided by McBride and Williams (2001) was that the standardisation of hearing can explain the notch at 6 kHz. Hearing sensitivity is not the same across the range of audiometric frequencies represented in the audiogram. The hearing-level (HL) reference levels are designed for testing hearing (Dobie, 2001). On the audiogram 0 dB HL is defined as the average threshold (across the frequency range) of hearing of normal hearing young adult subjects free of otologic disease (ANSI, 1996). The normalised shape of the audiogram should thus be a straight line, yet Robinson proposed that the reference standard at 6 kHz is set several dB too low with the result that a normal audiogram would have a notch at that frequency (Robinson, 1988). As McBride and Williams (2001) concluded; the association between the 6 kHz notch and NIHL is questionable and it is of limited use in diagnosing or describing NIHL.

Based on the notch criteria used (Coles, Lutman, & Buffin, 2000) no other high-frequency notch was observed. In a previous study conducted with data of a group of South African gold miners (n=780) it was also noted that the expected notch at 4 kHz was not observed (Soer, et al., 2002). In the current study the absence of a notch at 3 or 4 kHz was due to the very slight difference between these frequencies and 8 kHz (less than 10 dB). Differences between 3 or 4 kHz and 1 kHz were more than 10 dB in age groups 41 to 50 years, 51 to 60 years and 61 to 65 years. In a large study investigating 4 kHz notches in a group of military veterans (Wilson, 2011) mean notch depth at 4 kHz was consistently 20 to 26 dB across the age groups. It is clear that in the current study the presence of the notch at 4 kHz was influenced by the thresholds at 8 kHz. Scrutiny of the Soer, Pottas and Edwards (2002) data (South African gold miners) also revealed that thresholds at 8 kHz did not show a recovery at 8 kHz as could be expected in NIHL (Dobie, 2001). When mean thresholds at 8 kHz across the age groups for the current study (Noise Group 1) were compared to mean thresholds at 8 kHz for the Wilson (2011) study it was noted that 8 kHz revealed worse values for this study in the 16 to 30 and 31 to 40 age groups than the Wilson (2011) cohort (40 dB HL versus 22 dB HL and 43 dB HL compared to 33 dB HL). For the 41 to 50 and 51 to 60 age groups the opposite was observed. Mean thresholds at 8 kHz were better for this study than for the Wilson (2011) cohort, 43 dB HL versus 49 dB HL (31 to 40 years), 45 dB HL versus 61 dB HL (51 to 60 years) and 48 dB HL versus 70 dB HL (61 to 65 years). Participants of both these studies were exposed to occupational noise.

This trend, worse 8 kHz thresholds in younger groups and better 8 kHz thresholds in older groups, was also observed when median values were used. In the distribution tables supplied in Chapter 5 (Table (Table 5.16) a comparison between median values for this study at 8 kHz and the Hoffman, Dobie, Ko, Themann, & Murphy

(2010) data (proposed as a replacement for annex B (non-noise-exposed population) of the ISO 1990:1999) reveal slightly worse median values for the two younger age groups (25 to 34 and 35 to 44 years) in the current study and slightly better values for the older age groups (45 to 54 and 55 to 64 years) compared to that of the Hoffman, Dobie, Ko, Themann, & Murphy (2010) group. It seems that 8 kHz thresholds for the current study are more elevated than described in other studies up to age 45 and the progression of hearing loss at this frequency then slows down. The reason for this discrepancy is unclear. One possible contributing factor might be the high incidence of HIV (up to 30%) that has been reported in South African gold mines (Chamber of Mines, 2009). In a study investigating the effect of HIV on hearing of a group of HIV-infected outpatients (Chandrasekhar, et al., 2000) a significant elevation in thresholds was observed at 4 and 8 kHz. It is thus possible the relatively small difference observed between 3 or 4 kHz and 8 kHz, resulting in the absence of a notch in the current cohort, might be due to changes at 8 kHz because of HIV and the complex interactions due to opportunistic infections, drug use, associated risk profile and perhaps HIV itself (Bankaitis & Keith, 1995; Singh, et al., 2003; Sonnenberg, et al., 2005). The effect of HIV-related hearing loss risk on this and other frequencies as well as the progression of hearing loss at 8 kHz should be investigated in further studies.

6.4. Effect of age on hearing in different noise exposure groups

Some interesting results were observed when considering age and NIHL in this cohort. Hearing loss advanced as age increased. Categorising hearing according to age groups and working years shows worse hearing in all age groups with more years' exposure to noise and the most pronounced change is seen at 3 kHz. Deterioration in hearing slowed down in the high frequencies (3, 4 and 6 kHz) with advancement in age, but at 2 kHz deterioration seemed to be larger as age advanced. These findings will be discussed with reference to other published research in the following paragraphs.

6.4.1. Hearing loss increase with age and the effect of noise exposure time

As discussed in section 6.2.2 results of this study show an increase of prevalence of hearing loss in occupationally noise-exposed participants with age. Prevalence data from this study (figure 5.8) for moderate and severe hearing losses in Noise Group 1 were higher than in the No Noise Group for the age groups older than 50 years, consistent with the additive model of NIHL and ARHL where assessment of NIHL in older persons assumes that ARHL adds to a permanent noise-induced threshold shift (NIPTS). The additive model is incorporated by ISO 1990:1999 and assumes that the total hearing loss is the sum of ARHL and NIPTS minus a compression factor that is used when threshold shifts exceed 20 to 25 dB. This model has been used in several studies (Ciletti & Flamme, 2008; Hoffman, et al., 2010; Dobie, 2005; Dobie, 2008; Dobie, 2007; Flamme, et al., 2011; Pyykkö, et al., 2007). Age-related degenerative changes may affect neural fibres, stria vascularis, and inner and outer hair cells causing progressive hearing impairment (Ferrite & Santana, 2005) which support the hypothesis that these factors interact under an additive model.

To understand the changes of hearing in noise-exposed participants with advancement in age, participants were divided into the different age groups and then further divided into the number of years that they have been working. In all age groups, participants with more years of exposure to noise presented worse hearing across the frequency range than participants of the same age with less years of noise exposure. In all the age groups changes in thresholds with more working years were small when comparing working years in 5 year increments. Changes become more pronounced after 10 years of noise exposure (5 to 15 working years). This tendency was also noted in a smaller scale study on South African gold miners (n=866) (Soer, et al., 2002). In the Soer, Pottas and Edwards (2002) study it was noted that each following period of 10 years' service resulted in a deterioration of approximately 4-6 dB for all frequencies. Results for the current study showed that in the age group 31 to 40 years, the largest change was seen at 4 kHz between the group with 5 working years and 15 working years (a 10 dB difference). In the 41 to 50 years category the largest changes (between 5 working years and 15 working years) were 5 dB at frequencies 2, 3, 4, 6 and 8 kHz. In the age group 51 to 60 years the largest difference was seen at 3 kHz between the 5 working years group and the 15 to 20 years working group (10 dB). In the 61 to 65 years age group a 20 dB difference was observed at 3 kHz between participants with 0 to 5 working years compared to 15 to 20 working years, longer working years resulting in worse thresholds. This slow progression of NIHL has also been described previously (May, 2000; Sataloff & Sataloff, Occupational hearing loss, 2006). The 3 kHz frequency was most affected by noise in this cohort as can be seen across the age groups with more years' exposure to noise consistent with reports and research on NIHL (Osei-Lah & Yeoh, 2010; Gates, et al., 2000; McBride, Noise-induced hearing loss and hearing conservation in mining, 2004; Rabinowitz, et al., 2006; Wilson, 2011).

6.4.2. Differential deterioration of hearing across frequency with age increase

Results from this study have shown a decelerating time course of NIHL (non-linear growth pattern shown in figure 6.2). Hearing in people with NIHL, as with people without NIHL, worsens with time, but the relative contributions of noise and aging to the progression of the hearing loss have been described as a complex interaction (Dobie, 2008; Agrawal, et al., 2009; Gates, et al., 2000; Gates, et al., 2000). Results have shown greater differences in high-frequency hearing between the noise-exposed and control group in the younger age groups. This has also been described by results of previous studies (Dobie, 2008; Gates, 2000). Nelson et al. (2005) in their estimate of the burden of NIHL found peak impact of NIHL between 45 and 59 years. The reduced rate of change over time can be explained simply by the fact that hair cells lost from one cause (such as noise damage) cannot be lost again from another cause (such as age) (Gates, et al., 2000). Thus, one would expect less change over time in the thresholds of the frequency areas in the cochlea damaged by noise (Glorig, 1980).

Results of a longitudinal study (over 15 years) by Gates et al. (Gates, et al., 2000) investigating the changes in hearing thresholds in a group of elderly men previously exposed to noise (mean age at first test; 64 years, N=203) and a control group confirmed that hearing decelerated at a slower pace in the noise-affected frequencies over time. The non-linear growth pattern might be explained by research results of a study investigating the effect of initial NIHL on subsequent NIHL in animals (Perez, Freeman, & Sohmer, 2004). From the results of this study it appeared as if the animals were less sensitive to subsequent noise exposures. It was suggested that the lower effective intensity of the second noise for ears with a large initial pure tone shift was protecting the inner ear structures against subsequent hearing loss. Studies have shown that the effect of noise on hearing is most in the early years of exposure to hazardous noise levels but in later years (older than 65) the age-related hearing loss contributes more to the total loss of hearing than NIHL (Dobie, 2008; Pyykkö, et al., 2007b; Silverstein, 2008).

The Gates study showed for the first time that this decelerated growth pattern is true for the frequencies that are typically affected by NIHL (3, 4 and 6kHz) but showed an accelerated rate of loss over time in the frequency areas adjacent to the typical noise (Gates, et al., 2000). This accelerated loss was most apparent at 2 kHz and was independent of the age of the subjects and the degree of prior loss. When interpreting the results from the large cohort under investigation, in terms of these frequencies, this change was not seen (figure 5.9 and table 5.5). However, when a more homogeneous noise exposure group was used (drillers and administrative sub groups for control), including only black men, the decline in hearing sensitivity at 2 kHz with age was seen in median threshold values (figure 5.22). Median values for 2 kHz for the driller group showed no difference from the control group (administration) for the age groups 31 to 40 and 41 to 50 years but for the age group 51 to 60 years a 5 dB difference was present (more elevated for the drillers). Compared to this a difference was present for these two groups (drillers' thresholds more elevated) at 4 kHz in the younger age groups but no difference was observed at 4 kHz for the 51 to 60 years age group. The 95th percentile values showed no difference at 2 kHz for the age groups 31 to 40 years, but for the age groups 41 to 50 and 51 to 60 years differences of 8 and 5 dB were observed respectively. 4 kHz 95th percentile thresholds showed a difference of 5 dB between the driller and administration groups, but no difference for the age group 51 to 60 years.

These results confirm the findings of the Gates et al. (2000) study that noise-affected frequencies (4 kHz) in a noise exposed population show less difference to those of a control group with age, but that 2 kHz in a noise-exposed population (the drillers) are more affected in older age groups than those for the control group (administration). These authors suggest that the accelerated loss at 2 kHz is a progression of the noise damage in the absence of continuing noise exposure (Gates, et al., 2000). In response to the results of the Gates et al. (2000) study investigators addressed the issue in an animal model by comparing noise-induced and age-related hearing loss in groups of mice exposed to identically damaging noise sources but at different ages (Kujawa & Liberman, 2006). Results of the study suggest that pathologic changes initiated by early noise exposure (enough to damage but not destroy the cochlear structures) render the inner ears significantly more vulnerable to aging.

Results from this study across age groups were compared with data from a recent nationally representative survey in the United States (National Health and Nutrition Examination Survey, 1999–2004) (Hoffman, Dobie, Ko, Themann, & Murphy, 2010). The data from the Hoffman et al. study were presented in a distributional format and are offered as a possible replacement for Annex B in ISO 1990:1999 and ANSI S3.44. It was concluded that median thresholds were lower (better) in the 1999–2004 survey at 500, 3000, 4000, and 6000 Hz (8000 Hz was not tested in the 1959–1962 survey) across age and gender groups. Participants of this study were not exposed to occupational noise, making comparison between noise-exposed populations and these results possible. Median threshold values from the current study's Noise Group 1 are very similar to the medians of the Hofmann et al. (2010) cohort.

The largest differences were observed at 6 kHz, for the age group 36 to 45 years and 56 to 65 years for men. As explained earlier in this section 6 kHz difference could be due to calibration of the THD39 earphones. Median values of 2 kHz for the age groups 56 to 65 years were 6 dB worse for Noise Group 1 than for the Hoffman et al. (2010) participants. As discussed in the previous paragraph this again suggests that the ageing process is different in a noise-damaged cochlea with increased deterioration in frequencies adjacent to the noise-damaged frequencies (2kHz) (Gates, et al., 2000). Interestingly, the median thresholds for female participants of this study (Noise Group 1) were better compared to the Hoffman et al. (2010) medians for females for frequencies 2, 3, 4, 6 and 8 kHz for age groups 46 to 55 and 56 to 65 years. This is unexpected as more elevated thresholds could be expected from noise-exposed participants. To further investigate and understand these results it is important to discuss the effect of race on the outcomes and section 6.5 will discuss these effects on the data.

6.5. Effect of gender and race on hearing in different noise exposure groups

Results of this study showed that females exposed to noise levels above 85 dB A (irrespective of race) had better high-frequency hearing than men, who were also exposed to the same level of occupational noise. HFA346 medians were almost 10 dB better for the female subjects than for the male subjects and differed even more when 95th percentile values were used (more than 30 dB better for females than males). Threshold comparisons (medians) showed a marked difference between female hearing in the high frequencies (3-8 kHz) and male hearing with female medians 10 to 20 dB better across the high-frequency spectrum (figure 5.10). As with the HFA346 results the 95th percentile values per frequency for the high frequencies were between 20 and 35 dB better for females and males of the different races. Several previous studies have shown that females, exposed to high levels of noise, might be less susceptible to NIHL than males (Szanto & Ionesco, 1983; Le Prell, Hensley, Campbell, Hall III, & Guire, 2011; Rabinowitz, et al., 2006; Rabinowitz, et al., 2002; Ishii & Talbott, 1998).

It has also been well established that males and females, without known exposure to noise, require separate age-correction factors (ISO, 1990; ANSI, 1996). It has been described previously that in the general population (no known occupational noise exposure) males have poorer hearing than females across age and race groups in the high frequencies (Flamme, et al., 2011; Ciletti & Flamme, 2008; Hoffman, Dobie, Ko, Themann, & Murphy, 2010; Dreisbach, et al., 2007). It has however also been noted that men are more likely to have been exposed to gunfire, to have had noisy jobs, and perhaps to have been heavy smokers, or prefer louder music than females (Hoffman, Dobie, Ko, Themann, & Murphy, 2010; Le Prell, Hensley, Campbell, Hall III, & Guire, 2011). It might thus be possible that gender is a proxy factor for underlying systematic differences in exposure, environment, or susceptibility to NIHL. Results of a study by Szanto and Ionesco (1983) showed that females are likely less susceptible to NIHL as males in this study showed an accelerated hearing loss with increased noise levels compared to females. Analysis of the results of 5 742 participants participating in the United States of America National Health and Nutrition Examination Survey, 1999–2004, also confirmed poorer hearing with age in men than women (Hoffman, Dobie, Ko, Themann, & Murphy, 2010).

Interesting findings of two recent studies inspecting data from the United States of America National Health and Nutrition Examination Survey, 1999–2004 (N=5742) showed worse low frequency thresholds for females than for men (Flamme, et al., 2011; Hoffman, Dobie, Ko, Themann, & Murphy, 2010). Although worse hearing in the low frequencies was not seen in the results of the current study, differences in low frequency results between female and male participants (across race, Noise Group 1) were small or absent. Median values for frequencies 0,5, 1 and 2 kHz did not differ for black males and females and differed only with 5 dB for white females and males (Noise Group 1) compared to the larger differences (10-15 dB) for the high frequencies. For the 95th percentile values females presented with better thresholds (15-20 dB) for 1 and 2 kHz, but there was only a 5 dB difference at 5 kHz between black females and males, and no difference at 5 kHz for white males and females. A 1 dB difference (clinically irrelevant) was observed between male and female thresholds (across race) for the medians of the LFA512. For the 95th percentile values differences between male and female were 13 dB for black males and females and 5 dB for white males and females (female results better in both race groups).

Race has also been described as a proxy factor for underlying systematic differences in susceptibility to NIHL or ARHL. Several studies describing hearing in normal subjects (without noise exposure) have described better hearing thresholds in black versus white subjects (Dreisbach, et al.,, 2007; Henselman, et al., 1995; Flamme, et al., 2011). As early as 1931 better hearing thresholds have been described in black noise-exposed subjects compared to white counterparts (Bunch & Raiford, 1931). Subsequent studies investigating the effect of race on the hearing of noise-exposed participants have found similarly that black persons have better hearing thresholds across the high frequencies (Ishii & Talbott, 1998; Henselman, et al., 1995).

Several reports on the effect of eyecolour in susceptibility to NIHL (Carter, 1980; Ishii & Talbott, 1998; Carlin & McCroskey, 1980; Cunningham & Norris, 1982) indicate that individuals with blue eyes are more susceptible to noise-induced cochlear damage than are green or brown-eyed individuals which may be related to race since eyecolour is highly dependent on race. This clinical research suggests that melanin, especially in the stria vasclaris of the cochlea, appears to act as a protective agent (Ishii & Talbott, 1998). Results of this study for participants of Noise Group 1 for the HFA346 showed better hearing thresholds for black participants than for white participants across gender for medians and 95th percentiles. The difference for the HFA346 95th percentile values was more pronounced for the males (black versus white) than for the females (13 dB differences for males versus 3 dB difference across race for the females).

Interestingly, when the LFA512 results were compared black male participants displayed worse 95th percentile values than white male participants. This was not true for female subjects. When median values across individual frequencies were compared between genders of different races no differences were observed in any frequencies except for 4 kHz, where black males showed 5 dB better thresholds than white males and black females showed 5 dB better thresholds than white males. 95th Percentile values per frequency showed better hearing thresholds for black participants (across gender) at 3, 4, 6 and 8 kHz. However, black males showed 5 dB more elevated thresholds (worse) at 0,5, 1 and 2 kHz than white males. After correcting for age through ANCOVA, pairwise comparisons (F-test) indicated a significant difference between the black male group and white male group (p=0,00) for the low and high frequencies, with thresholds for the low frequencies (0.5, 1 and 2 kHz) significantly worse for black males and high frequencies (3, 4, 6 and 8 kHz) significantly better for black males compared to white males. The same “worse” thresholds for black participants were not observed for females.

Comparison of these results with the ISO 1990:1999 is not possible as Annex B does not distinguish between participants based on race. As the differences are very pronounced between black and white subjects (as discussed above) it can serve as a possible explanation for the unexpectedly similar median threshold results between the Hoffman et al. tables (Hoffman, Dobie, Ko, Themann, & Murphy, 2010) and results from Noise Group 1 (see table 5.20). As the Hoffman, Dobie, Ko, Themann, & Murphy (2010) data are for participants who were not exposed to occupational noise it is expected that it would be better than the data for participants of Noise Group 1 who have been exposed to occupational noise. Because of the prevalence of NIHL as shown earlier in this chapter greater differences were expected between the study results in comparison to a non-noise-exposed population. As the majority of this cohort are black participants and the majority of the NHANES 1999-2004 cohort

(Hoffman, Dobie, Ko, Themann, & Murphy, 2010) are white participants the effect of noise on the hearing thresholds could be masked.

ANSI S3.44 (1996) has an Annex C. Grouping results for different race and gender groups and the results from this study were compared to these results (table 5.21). Black participants from Noise Group 1 showed worse hearing thresholds at 6 kHz for age group 25 to 35 years, 3, 4 and 6 kHz for age group 36 to 45 years, 2 kHz for age group 46 to 55 years and 1, 2 and 3 kHz for age group 56 to 65 years. Keeping in mind that Hoffman and colleagues (2010) conclude that hearing thresholds are better in general based on the 1999-2004 data than for the ISO 1990:1999 data (ANSI S3.44 (1996) are virtually identical to ISO 1990:1999) it is possible that the difference between black participants for Noise Group and the ANSI S3.44 (1996) might be underestimating the effect of noise on hearing. Thresholds medians for white participants in Noise Group 1 of this study are very similar compared to the ANSI S3.44 (1996) Annex C.

Although it seems as if the distribution tables calculated from results of this study might be used as an alternative to other distribution tables caution must be taken when comparing these values to noise-exposed populations other than South African gold miners. As explained previously in this chapter (section 6.2) a relatively small difference between the Noise Group 1 and No Noise groups was evident (even though this difference was significant). The prevalence of hearing loss in the control group (No Noise Group) could be attributed to many variables unique to the gold mining community in South Africa (including leisure noise, HIV risk profile for hearing loss, TB etc). For different noise-exposed populations however, with different environmental and health variables, the distribution tables of No Noise Group (control group) could lead to underestimation of the effect of noise on hearing. With this caution in mind it is important to note that values supplied in distribution table format are unique and contribute greatly to the knowledge base as very few studies have explored the hearing of black participants exposed to occupational noise. A very large number of black males, exposed to occupational noise, participated in this study (N=17933). Based on results from an extensive review of published literature, this is the largest cohort of black male workers whose hearing thresholds has been described. A large cohort of black male gold mine workers not exposed to occupational noise also participated in this study (N=2790).

As the participants of the control group (No Noise) are from the same environmental background (non-occupational noise exposure) and share the same prevalence of HIV as participants of Noise Group 1 (underground noise-exposed) these tables could be used for comparisons with other noise-exposed groups in South African gold mines to identify the effect of noise on hearing. Very few studies have explored the hearing of black participants exposed to occupational noise in these environments. A very large number of black males, exposed to occupational noise, participated in this study (N=17933). Based on results from an extensive review of published literature, this is the largest cohort of black male workers that has been described in terms of their hearing thresholds. A large cohort of black male gold mine workers not exposed to occupational noise also participated in this study (N=2790). Values in these distribution tables are therefore unique and make an important contribution to this field.

6.6. Effectiveness of PLH to identify NIHL

In order to answer the hypothetical question relating to the effectiveness of the PLH to identify NIHL a few theoretical concepts will be highlighted in the following section. For a detailed literature review the reader is referred to Chapter 3, section 3.4.1. NIHL caused by high levels of occupational noise creates a hearing impairment or hearing handicap that might be defined as an interference with activities of daily living, especially speech communication (Dobie, 2001). For this reason NIHL has been compensable since the 1950s (Dobie, 2001). Most international agencies and states base the amount of handicap that a hearing loss can cause on results of the pure tone audiogram (see chapter 3). As early as 1942 it has been argued that a definition of hearing impairment should be easily understood, easily and quickly applied, free of complicated mathematical calculations, easily interpreted before a jury, designed for both ears, based on air-conduction results, weighted to give preference to the frequency range of the spoken voice and founded on the best available acoustical and clinical evidence (Carter, 1942).

In South Africa the calculation of percentage loss of hearing (PLH) is used to identify and compensate for NIHL (as per Instruction 171, COIDA, 2001). Hearing loss is defined as a PLH value (%). A baseline PLH is calculated based on the initial audiogram. A shift of 10% from baseline is compensable under law. Thus, the PLH value serves a dual purpose. Firstly the PLH values are used to determine the amount of financial compensation. Secondly PLH values are used to estimate the effect of occupational noise on hearing and thus serve as an indicator of NIHL.

As explained in paragraph one of this section, compensation schemes aim to reimburse the person for the handicap caused by the hearing loss. A thorough review of published literature and local reports were conducted but no published data could be found on the evidence supporting the development of the PLH calculation tables. Internal reports from the South African goldmines suggest that it might be based on the Australian method of determining PLH (Edwards, Unpublished doctoral thesis: Measurement of distortion product otoacoustic emissions in South African gold miners at risk for noise-induced hearing loss, 2010). The PLH calculations used in Australia were developed by Macrae (1988) for the National Acoustical Laboratories (NAL). These tables were designed to give more weight to frequencies that produced the highest degree of hearing handicap when impaired. This method is very similar to the South African PLH method, but for the inclusion of 1.5 kHz. Weighting is based on the estimated contribution of the different audiometric frequencies to the hearing handicap. Based on estimations awarding the maximum potential contribution to the handicap to 1 kHz and the lowest contribution to 3 and 4 kHz, PLH weighting is calculated (Greville, 2010; Macrae, 1988). With reference to the dual function of the PLH it can be assumed that the PLH as a means of awarding compensation should thus be a fair judgement of hearing handicap. But, as NIHL typically causes high-frequency hearing loss (as has also been shown through these results) it is questioned whether PLH is a sensitive measure to estimate the presence of NIHL.

Another widely used method to calculate hearing impairment (most American states use or permit its use) is the AMA (1979) method (Dobie, 1992; AAA, 2003; AMA, 1955). This method incorporates frequencies 0,5, 1, 2, and 3 kHz with all these frequencies evenly weighted. As high frequencies are typically affected by NIHL and this method uses one high frequency amidst three lower frequencies it is even possible that the AMA (1979) method underestimates the presence of NIHL. When comparing the PLH values and the AMA values of participants in Noise Group 1, results of this study showed that the PLH values do not correlate with AMA values.

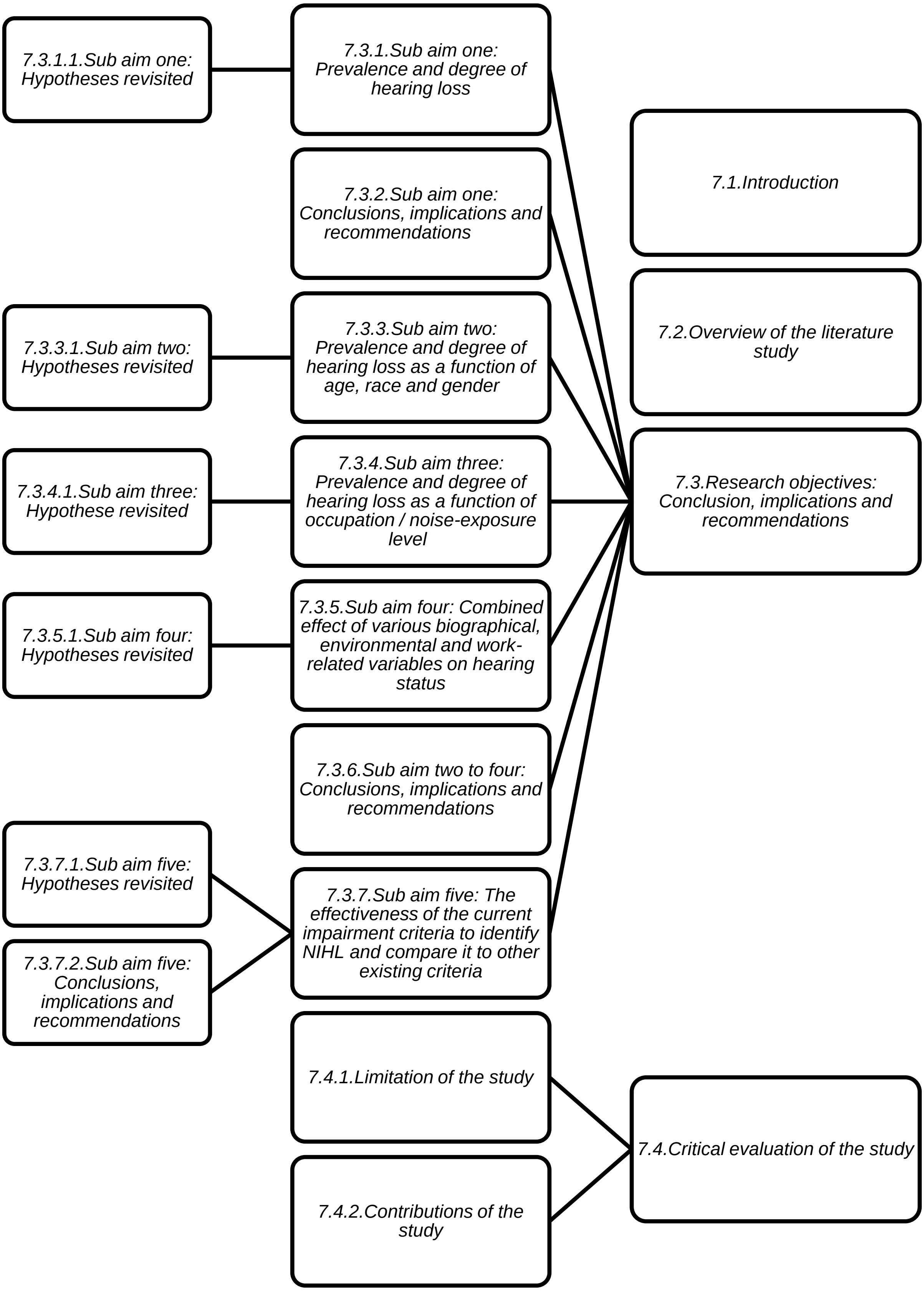
For instance, the group of participants with PLH values between 21 and 25 % yielded an average AMA value of 12%.

These values were also interpreted in terms of possible compensation claims. PLH values of larger than 10 would be compensable compared to the American compensation system that would reward any AMA value larger than 0%. Results show that a large group (N=48476) of participants would not be compensated by either the AMA or PLH formulae. A group of 6 295 would be compensated based on both sets of results. A group of 2 648 participants would be compensated if the AMA formula was used but would not have been compensated based on the PLH values. Conversely, only 294 participants would have been compensated by the PLH and not the AMA. Results for this group showed a HFA346 average of 35 dB and a LFA512 group average of 25 dB. These results indicate that hearing loss in the high frequencies would have to exceed 35 dB before the PLH formula would consider it a compensable hearing loss, yet the risk for NIHL is apparent. PLH formula might be effective to indicate the reward that should be allocated for compensation, but not to indicate the presence of NIHL.

6.7. Summary

The discussion focused on the prevalence of hearing loss (high and low frequency) for the noise-exposed groups compared to other published data and the unique control group. Effects of age, working years (noise-exposed years), race and gender on hearing were considered and discussed. PLH as an indicator of NIHL was considered and compared to other well-accepted criteria. All these findings will be highlighted and summarised in Chapter 7.

7. Conclusion



7.1. Introduction

While research in the area of noise-induced hearing loss (NIHL) is hindered by variable definitions of damaging noise levels, variable classifications of hearing impairment and several factors co-existing or aggravating NIHL, the interest in NIHL as a preventable cause of hearing loss remains current (Agrawal, et al., 2010; Dobie, 2008). In South Africa objectives set for industry by government and role players have further emphasised the need for research in the area of occupational NIHL. This study endeavoured to summarise available literature in this area with reference to the prevalence of occupational NIHL, characteristics of NIHL, the effect of variable noise sources on hearing, specific frequency effects of NIHL, as well as the effect of age, gender and race on NIHL. A large, representative dataset was made available for this research study by a South African gold mining group and this allowed for investigation of several variables influencing NIHL such as age, race, gender, noise exposure, and noise exposure time. Results from this quantitative research study lead to assumptions about NIHL in this cohort that can serve to guide classification or definition of NIHL in the South African context.

The aim of this chapter is therefore to revisit the research objectives and hypotheses and to draw conclusions, describe implications and to make recommendations for further research. The chapter concludes with a critical evaluation of this study and a delineation of the contributions of this study.

7.2. Overview of the literature study

The literature review, provided in Chapter 2 and 3 framed the research objectives. Figure 7.1 represents the aspects reviewed and discussed though the literature study in Chapters 2 and 3.

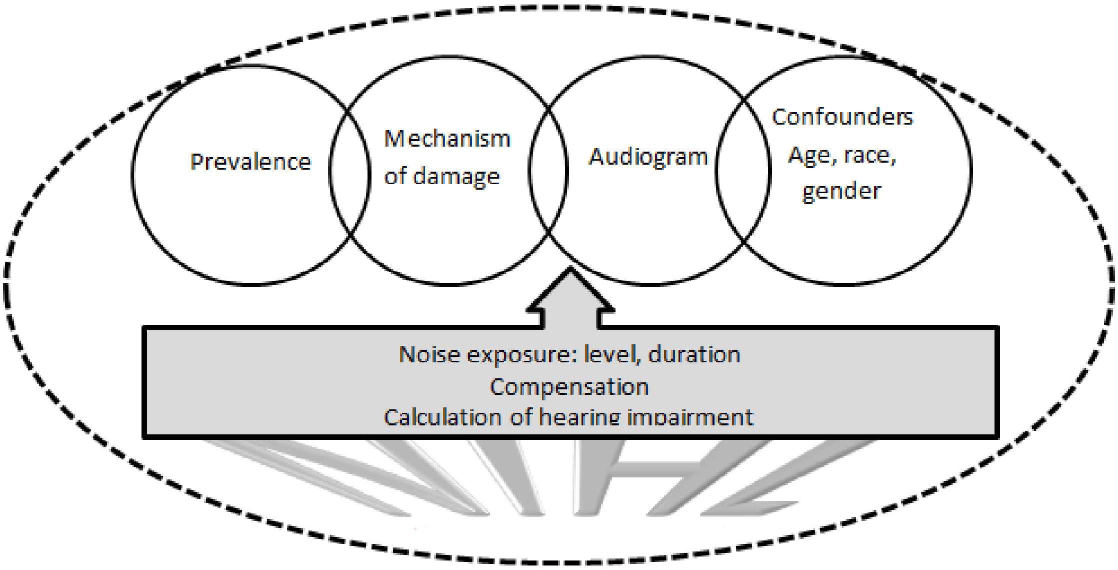


Figure 7-1 Main aspects reviewed in the literature study in Chapters 2 and 3

In Chapter 2 the following critical aspects of NIHL were addressed and the main points are summarised below:

- A historical overview of NIHL demonstrates that noise has been affecting hearing for many years and its damaging influence in hearing has increased with the industrial revolution and the development of noisy equipment. Previously audiologists and health care providers focused on treatment of NIHL but recently emphasis has shifted to the prevention thereof.

- Despite preventative measures being taken NIHL is still prevalent world-wide. The occurrence of NIHL in South African mines was also described, where the prevention of NIHL has taken top priority along with certain lung diseases (Anglogold Ashanti, 2011).

- The mechanism of damage to the cochlea due to excessive noise was described and discussed in detail. Understanding the mechanism of NIHL lays a foundation for better preventative strategies.

- Although there is general agreement about the high-frequency nature of NIHL, the literature review demonstrated that there is still uncertainty about the so-called “noise notch” and the sustained effect of noise across the frequency spectrum without further exposure to damaging noise (Rabinowitz, et al., 2006; Wilson, 2011; Gates, et al., 2000).

- Although individual susceptibility to NIHL was described in literature, several factors co-exist with NIHL and can either be a direct cause of hearing loss or aggravate the effect of noise on hearing (Agrawal, et al., 2010). The exact nature of the effect of these variables or the interaction with NIHL is unclear. Age is a factor that was described as the number one cause of hearing loss in adults (Dobie, 2008). The relative contributions of noise and aging to the progression of the hearing loss were described as a complex interaction (Dobie, 2008). Race and gender were described as factors influencing either the susceptibility to NIHL or hearing in general (Ishii & Talbott, 1998; Henselman, et al., 1995; Robinson, 1988; Cooper, Ear and race effects in hearing.Health and Nutrition Examination Survey of 1971-75: Part I, 1994).

In Chapter 3 the available literature was scrutinised and the following conclusions reached:

- A historical overview was given on noise measurements and surveys that culminated in the development of noise measurement scales and damage risk criteria.
- Based on large-scale surveys before the introduction of hearing conservation programmes, most noise standards (internationally) set a level of 85 dB A as the limit of daily noise exposure (8 hours working day) with a 3 dB exchange rate, leading to a halving of the time limit with every 3 dB increase in noise levels (ANSI, 1996; ISO, 1990; NIOSH, 1998; SANS10083:2007, 2007). Controversies regarding these noise and time limits were highlighted (Sataloff & Sataloff, 2006; Dobie, 2001).
- As compensation for hearing loss caused by noise is an important incentive underlying definitions of hearing impairment, NIHL as a compensable disease was discussed. It was clear that the definition of NIHL, in terms of frequencies affected and the role of co-variables (such as age), informs the definition of hearing impairment (Dobie, 2001). To identify the possibility of hearing deterioration due to excessive noise, high frequencies would be included in a

hearing impairment definition (Rabinowitz, et al., 2006). Yet, for compensation purposes hearing impairment should also be defined in terms of the hearing handicap caused (Dobie, 2001). Controversy exists in the field whether age-related hearing loss should be taken into account when defining hearing impairment for compensation purposes. Proponents for age correction argue that the individual’s total hearing loss should almost always be treated as the sum of at least two components, NIPTS and age-related permanent threshold shift (ARPTS) (Davis, 1989). Proponents against age correction criticise it because compensable hearing impairment might be “downgraded” below compensation level (Dobie, 2008).

This literature study provided the foundation for the empirical part of the study and structured the research objectives as they were defined in Chapter 4.

7.3. Research objectives: Conclusion, implications and recommendations

The research objectives were presented in Chapter 4 and will now be discussed individually as aims and sub aims. The sub aims of the study were constructed in order to reach the main aim of the study namely to describe the prevalence and degree of NIHL in a group of gold miners in South Africa and to evaluate the effectiveness of the current RSA criteria to identify NIHL.

The following figure 7-2 serves as a summary of main conclusions. In the sections following the figure these conclusions will be discussed under the separate sub aims presented.

NIHL is prevalent in noise-exposed groups	• High-frequency hearing loss was also present in the control group • Greatest differences in prevalence of hearing loss were observed at 3,4 kHz and age group 36 to 45 years • 8 kHz revealed worse thresholds in the cohort than expected and decline slowed down with age • A notch was observed at 6 Hhz, but should be considered with caution • No other notch was present
Effect of age on hearing	• NIHL was affected by age • High-frequency thresholds showed a non-linear growth pattern with age • 2 kHz showed more decline with age in the noise-exposed population compared to the control group • Hearing deteriorated more across age groups with more noise-exposed years • This deterioration was most visible after 10 to 15 years of noise exposure • The greatest decline in hearing across age groups with longer working years was at 3 kHz
Effect of gender on hearing Effect of race on hearing Combined effect of all factors on hearing	• Females had better hearing thresholds than males in the noise - exposed and control groups • Black females had better hearing thresholds than white females • Black males had significantly better high-frequency hearing than white males across the same noise-exposure categories • Black males had significantly worse low-frequency hearing than white male counterpart
Effectiveness of PLH to identify NIHL PLH in comparison with other risk criteria	• PLH is not an effective indicator of high-frequency hearing loss and thus of NIHL • PLH could be an effective indicator of hearing handicap • PLH values showed poor correlation (shown through statistical analyses) with other well-accepted hearing impairment criteria

Figure 7-2 Summary of conclusions based on the results and discussion (chapter 5 and 6) of this study

7.3.1. Sub aim one: Prevalence and degree of hearing loss

7.3.1.1. Sub aim one: Hypotheses revisited

Various conclusions can be drawn from the results of the empirical study pertaining to the prevalence of NIHL in South African gold mines. A significant difference between the prevalence of high-frequency hearing loss, indicative of NIHL, was evident in the noise groups compared to the control group. The following hypotheses, null and alternative, were defined for sub aim one and the conclusion provided:

$H1_0$	There is no difference between the prevalence and degree of hearing loss for the gold miners exposed to high levels of occupational noise and a control group. **Not true**
$H1_a$	Gold miners exposed to high levels of occupational noise will have a higher prevalence and greater degree of hearing loss than a control group not exposed to occupational noise. **True**

The null hypothesis is therefore rejected and the alternative hypothesis is *accepted.*

7.3.2. Sub aim one: Conclusions, implications and recommendations

- NIHL was prevalent in noise-exposed groups. On average the cohort had a prevalence of 20,5% high-frequency hearing loss greater than 30 dB HL (HFA346) compared to 16% for the control group. When these prevalence values were calculated per age group percentages of participants with hearing loss greater than 30 dB HL were 18% for age groups 36 to 45 years compared to 14% for the control group, almost 40% for the age group 46 to 54 years and 63% for age group 56 to 65 years compared to 37 and 62% for the control group. Although the prevalence of high-frequency hearing loss, indicative of NIHL, was significantly higher for the noise-exposed groups compared to the control group high-frequency hearing loss was also prevalent in the control group. This could indicate a largely effective hearing conservation programme but could also be due to factors influencing hearing in the larger cohort such as HIV and its associated risk profile. *These variables should be carefully identified and the effect on hearing should be evaluated in follow-up research investigations.*

- Comparison to other international surveys in terms of prevalence of NIHL was hindered by differing definitions of hearing impairment, different frequencies included in calculations, different stipulated degrees of hearing loss as well as the presence of confounding variables such as age and race. On the whole it seemed that prevalence of hearing loss was comparable to other data available from developing countries, but that NIHL was more prevalent than in developed countries. The prevalence of NIHL was greatly affected by age; prevalence of high-frequency hearing loss increased with advancement in age.
- Greatest differences in prevalence of hearing loss between the noise-exposed and control group were observed at 3 and 4 kHz in the age group between 36 to 45 years of age.
- Thresholds at 8 kHz were worse than expected and decline slowed down with age. *The effect of confounding variables on 8 kHz should be investigated further.*
- The only high-frequency notches observed were at 6 kHz, but because of several factors these results should be interpreted with caution. As highlighted in the discussion as well as literature chapters (2 and 6) it has been noted in publications that the observed 6 kHz notch can be attributed to an error in the reference value for audiometric zero when calibrating TDH-39 headphones on an NBS-9A (6 cm3) acoustic coupler (Hoffman, et al., 2010; Lawton, 2005; Lutman & Davis, 1994). Questions about the standardisation of hearing at 6 kHz have also been raised (McBride and Williams; 2001). *Results of this study suggest that the reference value for audiometric zero at 6 kHz should be revisited.*

7.3.3. *Sub aim two:* Prevalence and degree of hearing loss as a function of age, race and gender

7.3.3.1. Sub aim two: Hypotheses revisited

As the variables stipulated in sub aims two to four impacted the same results and were discussed as the net effect of all these variables on the hearing of gold miners the conclusions drawn for these three sub aims will also be done concurrently after the specific hypotheses had been reconsidered.

The following hypotheses were defined for sub aim two and the answers provided:

$H2i_0$	There is no difference between the prevalence and degree of hearing loss for gold miners of different ages. **Not true**
$H2i_a$	Gold miners of greater age will have a higher prevalence and a greater degree of hearing loss than younger gold miners. **True**
$H2ii_0$	There is no difference between the prevalence and degree of hearing loss for male and female gold miners. **Not true**
$H2ii_a$	Male gold miners will have a higher prevalence of and a greater degree of hearing loss than their female counterparts. **True**
$H2iii_0$	There is no difference between the prevalence and degree of hearing loss for gold miners of different races. **Not true**
$H2iii_a$	White gold miners will have a higher prevalence and a greater degree of high frequency hearing loss than their black counterparts. **True**

In all instances the null hypotheses were rejected and the alternative hypotheses were accepted. Male gold miners showed a higher prevalence and a greater degree of hearing loss than their female counterparts, gold miners of greater age revealed a higher prevalence and a greater degree of hearing loss than younger gold miners and white gold miners showed a higher prevalence of and a greater degree of high-frequency hearing loss than their black counterparts. As explained earlier in this section, conclusions will be discussed together with the conclusions of sub aims 3 and 4 in section 7.3.6.

7.3.4. Sub aim three: Prevalence and degree of hearing loss as a function of occupation / noise-exposure level

7.3.4.1. Sub aim three: Hypothese revisited

The following hypotheses were formulated for sub aim three:

$H3_0$	There will be no difference in prevalence and degree of hearing loss as a function of occupation / noise-exposure level. **Not true**
$H3_a$	Gold miners exposed to more occupational noise for a longer period will have a higher prevalence and a greater degree of hearing loss than participants exposed to lower levels of occupational noise. **True**

Across all age categories it was demonstrated that the longer the time period (measured in 5 year increments) of exposure to excessive noise in the workplace the more elevated the hearing thresholds across the frequency spectrum. It was also demonstrated that participants from occupational groups with higher levels of noise exposure (drillers) showed thresholds more elevated than those from the participants of the general Noise Group 1. The null hypothesis was therefore rejected and the alternative hypothesis was accepted. Conclusions will be discussed together with those of sub aims 3 and 4 in section 7.3.6.

7.3.5. Sub aim four: Combined effect of various biographical, environmental and work-related variables on hearing status

7.3.5.1. Sub aim four: Hypotheses revisited

The following hypotheses were formulated for sub aim four:

$H4_0$	There will be no difference in degree of hearing loss as a function of different biographical, environmental or work-related variables. **Not true**
$H4_a$	Hearing status will be influenced by different biographical, environmental or work-related variables. **True**

Results showed that hearing status was influenced by different biographical, environmental or work-related variables. It was shown that age affects the hearing thresholds of the noise and control groups. Within the age groups thresholds were affected differently for different noise-exposure groups (the larger cohorts but also homogeneous exposure groups) and for different exposure times. The exact nature of this interaction is difficult to define, but it was clearly demonstrated by certain tendencies that one or more factors were at play additionally to the NIHL in the cohort.

To further highlight the combined effect of various variables on the hearing status, shown by the results, threshold distributions of gold miners were compared to demographically matched control groups to evaluate if hearing thresholds are typical for a matched demographic group. Comparisons with a matched demographic group can be used to describe whether a person’s status is typical (Flamme, et al., 2011). A synthesis of reported effects culminated in the development of the ISO 1990:1999 and the nearly identical ANSI S3.44 (1996) guidelines. Both international (ISO 1990:1999) and United States of America (ANSI S3.44-1996) standards describe the distributions of hearing thresholds (10th, 50th, and 90th percentiles, for 0,5 to 6 kHz) associated with age and gender and were used for comparison with current data together with the proposed replacement for Annex B (Hoffman, Dobie, Ko, Themann, & Murphy, 2010). Results were summarised in distribution tables for the cohort of this study, stratified in age, gender, noise exposure and race categories.

7.3.6. Sub aim two to four: Conclusions, implications and *recommendations*

In the following section conclusions from results pertaining to sub aim 2 to 4 will be dicussed.

- It was clearly demonstrated that NIHL was affected by age. All the results showed that hearing loss for more advanced age groups were more severe as the participants increased in age. This increase seemed to slow down with older age groups, showing a non-linear growth pattern with age. This was true for all racial and gender groups.
- Results of two homogeneous noise-exposure groups were used (drillers and administrative sub groups for control), including only black men; the decline in hearing sensitivity at 2 kHz with age was seen in median threshold values. These results confirm the findings of other studies that noise-affected frequencies (4 kHz) in a noise-exposed population show less difference to those of a control group with age, but that 2 kHz in a noise-exposed population (the drillers) is more affected in older age groups than those for the control group (administration).
- In all age groups, participants with more years of exposure to noise presented poorer hearing across the frequency range than participants of the same age with less years of noise exposure. In the age group 31 to 40 years, the largest change was seen at 4 kHz between the group with 5 working years and 15 working years (10 dB difference). In the 41 to 50 years category the largest changes (between 5 working years and 15 working years) were at frequencies 2, 3, 4, 6 and 8 kHz. In the age group 51 to 60 years the largest difference was seen at 3 kHz between the 5 working years group and the 15 to 20 years working group (10 dB). In the 61 to 65 years age group a 20 dB difference was observed at 3 kHz between participants with 0 to 5 working years compared to 15 to 20 working years, longer working years resulting in worse thresholds. In all the age groups changes in

thresholds with more working years were small when comparing working years in 5-year increments. Changes become more pronounced after 10 years of noise exposure (5 to 15 working years).

- Results of this study showed that females exposed to noise levels above 85 dB A (irrespective of race) had better high-frequency hearing than men, who were also exposed to the same level of occupational noise. Threshold comparisons (medians) showed a marked difference between female and male hearing in the high frequencies (3-8 kHz). Female median values were 10 to 20 dB better across the high-frequency spectrum than those for the males.
- Low-frequency hearing thresholds were worse for black male participants than for white male participants. This was not true for female subjects.
- Results of this study for participants of Noise Group 1 for the high-frequency thresholds showed better hearing thresholds for black participants than for white participants across gender for medians and 95th percentiles. The difference for the high-frequency results was more pronounced for the males (black versus white) than for the females (13 dB differences for males versus 3 dB difference across race for the females).
- As explained previously in this chapter (section 7.3) a relatively small difference between the Noise Group 1 and No Noise groups was evident (even though this difference was significant). For different noise-exposed populations, however, with different environmental and health variables, use of the distribution tables of No Noise Group (control group) could lead to underestimation of the effect of noise on hearing. With this caution in mind it is important to note that values supplied in distribution table format are unique and contribute greatly to the knowledge base as very few studies have explored the hearing of black participants exposed to occupational noise. A very large number of black males, exposed to occupational noise, participated in this study (N=17 933). Based on results from an extensive review of published literature, this is the largest cohort of black male workers whose hearing thresholds has been described. A large cohort of black male gold mine workers not exposed to occupational noise also participated in this study (N=2 790).

- As the participants of the control group (No Noise) are from the same environmental background (non-occupational noise exposure) and share the same prevalence of HIV as participants of Noise Group 1 (underground noise-exposed) these tables could be used for comparisons with other noise-exposed groups in South African gold mines to identify the effect of noise on hearing.

7.3.7. Sub aim five: The effectiveness of the current impairment criteria to identify NIHL and compare it to other existing criteria

7.3.7.1. Sub aim five: Hypotheses revisited

The following hypotheses were formulated for sub aim five:

$H5_0$	The current impairment criteria (RSA) is effective in identifying NIHL **Not true**
$H5_a$	The current impairment criteria (RSA) is not effective in identifying NIHL **True**

Results from this study showed that the high frequencies were affected by NIHL and that the greatest changes to hearing with longer exposure to excessive noise in the workplace were seen at 3 and 4 kHz. The PLH weights the low and mid-frequencies more than the high frequencies and it is therefore concluded that it is not an effective measure for identifying NIHL.

7.3.7.2. Sub aim five: Conclusions, implications and *recommendations*

The following conclusions were drawn from the results of this study and for this sub aim:

- These results indicate that hearing loss in the high frequencies would have to exceed 35 dB before the PLH formula would consider it a compensable hearing loss, thus early onset NIHL would be ignored. As results clearly showed that high frequencies were most affected by occupational noise exposure it is imperative in a formula designated to identify NIHL to consider high-frequency hearing loss. The PLH formula might be useful to indicate the reward that should be allocated for compensation, as the frequencies important for hearing speech are weighted more than the high frequencies but it is not effective to indicate the presence of NIHL.

- Baselining, as it is mandated for South African mines, is critical as any subsequent changes in hearing after a period of noise exposure could be recognised early. Yet, as the PLH method is not sensitive for high frequencies it is possible that even with baseline hearing testing, real changes in hearing due to noise exposure might only be recognised when the middle frequencies become affected.

- Even though results have shown that age affects hearing and that an additive relationship between NIHL and ARHL exists, age correction is not recommended. Age correction has been criticised because the compensable hearing impairment might be “downgraded” below compensation level which is fundamentally unfair because of the implication that all of the impairment is to be blamed on age-related hearing loss. Results of this study have clearly demonstrated that some frequencies are less affected by noise with age, but that adjacent frequencies (such as 2 kHz) are more affected with age in a noise-exposed group than in a control group. This suggests that age-related hearing loss will also be affected by excessive occupational noise exposure.

- Because of the relatively small difference in prevalence of high-frequency hearing loss between the noise-exposed and the control groups it is possible that other agents might be affecting hearing and research in this area is critical.

Based on these comments the following model for identifying NIHL and allocating compensation benefits in South African mines are discussed in the following paragraph. Currently the following process is mandated by the Compensation for Occupational Injuries and Diseases Act (COIDA), No. 130 of 1993. Circular Instruction No. 171(2001): The date of the commencement of the disease is stated as the date of the first audiogram showing an increase from the baseline in the percentage loss of hearing (PLH) by 10% or more. The PLH values are calculated using the results of the baseline audiogram and the diagnostic audiogram using the weighted calculation tables (Appendix C). Persons to be submitted for compensation consideration would be: Employees whose PLH values have deteriorated by more than 10% PLH from the baseline audiogram or employees who have more than 10% PLH and for whom no baseline is available. The better of the two diagnostic audiograms is used. If a baseline PLH is available this value is subtracted from the PLH obtained. If a baseline PLH is unavailable the PLH is taken as the value from which permanent disability will be calculated.

COIDA (2001) stipulated that the baseline PLH, subtracted from the better diagnostic audiogram PLH, determines the hearing loss for which the Compensation Commissioner or the insurance association or employer is responsible. Yet, as discussed earlier it is likely that other factors have caused the low-frequency hearing loss, or than NIHL is overlooked because of the use of the PLH as a hearing impairment formula. For this reason the following two-step process is recommended to identify NIHL (and liability) and to allocate compensation benefits:

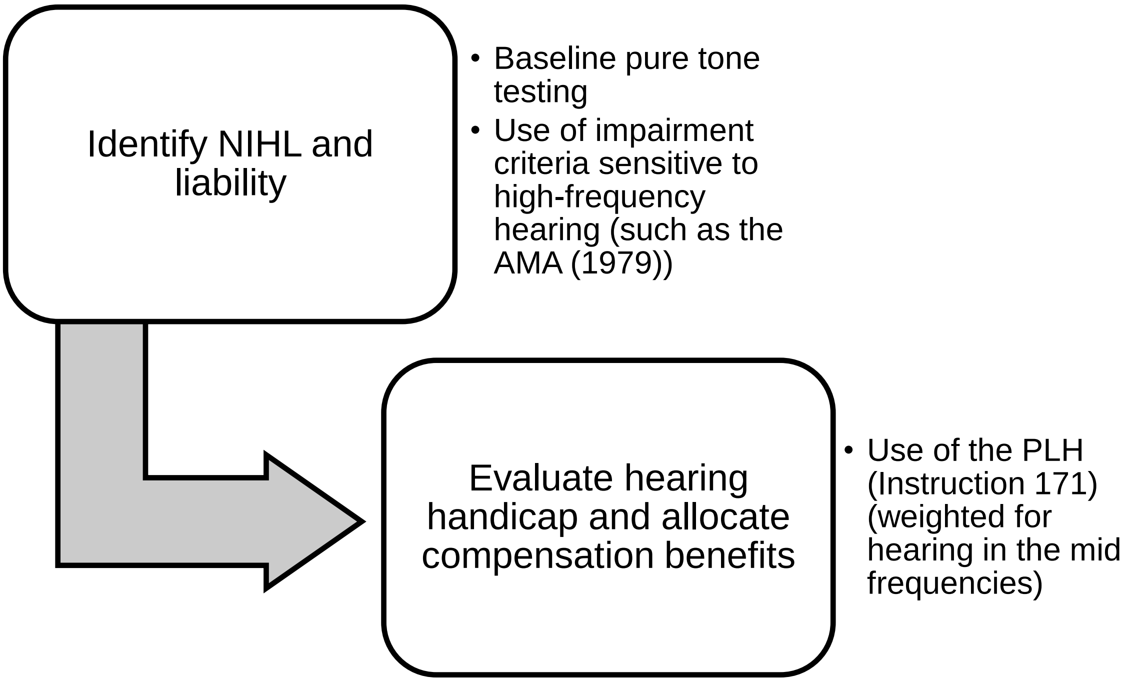


Figure 7-3 Two-step audiological process recommended for South African mines to identify NIHL and allocated compensation

As shown in figure 7-3, it is recommended that the identification of NIHL and the definition of hearing handicap should be two different processes. Hearing impairment due to NIHL should be calculated first, without taking into account the contribution of age to the hearing loss, and without mid-frequency weighting. Employees who show a specified difference in percentage of hearing loss based on these criteria should then be liable for compensation. Hearing handicap (on which compensation is then based) can be calculated (with use of the PLH) for the group of workers identified with a specified percentage of NIHL.

7.4. Critical evaluation of the study

7.4.1. Limitation of the study

Although the study was concluded in the best manner possible, with due consideration to the optimal research design and methodologies to address the research aims, certain limitations need to be noted. These limitations include the following:

- *Research participants/ data organisation:* A very large dataset consisting of 223 873 audiograms were made available for this research study. Errors in data entries (described in detail in chapter 4.9.2) made many of the audiograms included in the original dataset unusable (after data cleaning 52 432 audiograms were deleted). As a result data cleaning took a considerable amount of time and increased the cost of this study. The high cost and prolonged data-cleaning time might hamper future research with similar or future datasets of these mines. Training of personnel responsible for feeding the information into the software should be considered carefully to eliminate these errors in future.

- *Research participants/ data organisation:* Apart from incorrect entries as highlighted above data entry was not always complete. (See chapter 4 for detail.) For some participants, information was not complete with reference to race, gender, noise exposure and engagement date. Because of participants' unique employee numbers it was nevertheless possible to extract this information by combining the audiogram dataset with other datasets available from the mines. For some participants, however, this information was not available in any of the datasets and rendered these audiograms unusable for analyses within the different groups. As a consequence the complete sample of certain groups (such as white males in Noise Group 1) could not be used and the group for which data was available (convenience sample) was used. Because of the very large sample size of the cohort (from which these purposive samples were selected), numbers of participants with the relevant information were still sufficient to do statistical analyses and statistical significance could be obtained. As noted above training of personnel responsible for feeding the information into the software programme should be a priority.

  The lack of information on HIV status of participants hindered interpretation of results. Results indicated that high-frequency hearing loss was also prevalent in the control group. Because of the very large sample size, factors that affect a relatively small number of participants should not affect the results. However, since very limited information is available about the prevalence of HIV in this cohort, it is possible that a large number of participants might have HIV and that results might have been influenced. It is estimated that a large group of gold miners might have HIV (Chamber of Mines, 2009). It could be deduced that there is a relationship between the presence of HIV and its associated risk profile amongst participants and their hearing thresholds. Yet, because of confidentiality information about HIV status was not made available. Although the effect of HIV and its associated risk profile on the hearing of gold miners were not the focus of this study this should be explored further in future research studies.

- *Research design:* A limitation of the retrospective cohort design of this study was the lack of control over some confounding variables. Where these variables were known, such as age, statistical methods were employed to "control" for the influence of these variables. However, it is possible that unknown variables might have also influenced the results, such as described in the section above, and as a result of the retrospective nature of the collected data those could not be controlled for.

7.4.2. Contributions of the study

This study set out to describe the hearing of gold miners in South Africa in terms of the prevalence of NIHL and the hearing thresholds of the gold miners.

- To date this is the largest study conducted in a South African gold mine investigating the hearing thresholds and prevalence of NIHL in a cohort of gold miners (N=57 714).
- Established through an extensive literature search, this study is the largest study investigating NIHL conducted in any gold mine, nationally or internationally.
- Very few studies have explored the hearing of black participants exposed to occupational noise. A very large number of black males, exposed to occupational noise, participated in this study (N=17 933). Based on results from an extensive review of published literature, this is the largest cohort of black male workers whose hearing thresholds have been described. A large cohort of black male gold mine workers not exposed to occupational noise also participated in this study (N=2 790). Values supplied in distribution table format (Chapter 5) are therefore unique and contribute greatly to the knowledge base.

- The study embarked on an in-depth evaluation of hearing in terms of prevalence, high- and low-frequency averages, degree and hearing thresholds across the frequency spectrum. An exploration of the database for published research only derived a few articles relating to noise-induced hearing loss in a South African context. Only three studies investigated NIHL and pure tone audiogram characteristics in South African gold miners (Vermaas, et al., 2007; Soer, et al., 2002; Hessel & Sluis-Cremer, 1987). The Hessel & Sluis-Cremer (1987) study utilised the data of 2 667 white gold miners to describe the prevalence and hearing thresholds of this cohort. Results were not described in terms of race or gender. No data for black miners were included in that study. Sample size for the Soer, Pottas, & Edwards (2002) study was 866 participants whose audiogram results were categorised in terms of participants' age and years' of service but not with reference to race and gender. The Vermaas, Edwards, & Soer, (2007) study (n=339) described the relationship between hearing handicap and audiogram configuration but did not aim to describe hearing thresholds across the frequency spectrum. The current study is the first of its kind in South Africa grouping participants based on age, race and gender as well as working years and specific noise exposure groupings.

- Results from this study added to the body of knowledge in the field of NIHL by adding more evidence in support of certain findings, identifying tendencies not previously described and creating more questions to be answered by empirical research.

- South African legislation relating to industrial hearing testing and compensation for occupational NIHL mandates the use of the PLH (COIDA, 2001) as a calculation of hearing impairment. Based on the results from this empirical study suggestions were made to identify NIHL more effectively in South African mines and industry, whilst still compensating sufficiently. Findings from this empirical study can be used to inform clinical practice in audiology as well as legislation pertaining to NIHL.

7.5. Suggestions for further research

During the conclusion of the specific sub aims, recommendations for further research were made in the specific sections pertaining to the sub aims. These suggestions will be summarised below. This study highlighted the following areas where further research endeavours are needed:

- The effect of HIV and its related risk profile on the hearing of gold miners.
- Factors influencing hearing in a community of gold mine employees not exposed to occupational noise.
- The progression of hearing loss at 8 kHz in a group of gold miners.
- Low-frequency hearing in a black population.
- Results of this study suggest that the reference value for audiometric zero at 6 kHz should be revisited.
- Effective training material for mine personnel about the importance of capturing data accurately.
- The utility of DPOAEs as part of a screening test battery to identify early damage to the cochlea in a large population.

7.6. Final comments

World Health Organisation, (WHO), 1997:

> "Exposure to excessive noise is the major avoidable cause of permanent hearing impairment worldwide. Noise-induced hearing loss is an important public health priority because, as populations live longer and industrialisation spreads, NIHL will add substantially to the global burden of disability."

Albert Szent-Gyorgyi, 1893-1986, Nobel Prize winner for Medicine 1937:

> **"**Research is to see what everybody else has seen, and to think what nobody else has thought."

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Appendixes

Appendix A

Ethical clearance and collaboration agreements

Appendix B

Structure and mandate of the Mine Health and Safety Council (MHSC)

Appendix C

COIDA, Compensation for Occupational Injuries and Diseases Act, No. 130 of 1993. Circular Instruction No. 171, 2001

Appendix D

Equipment calibration certificate