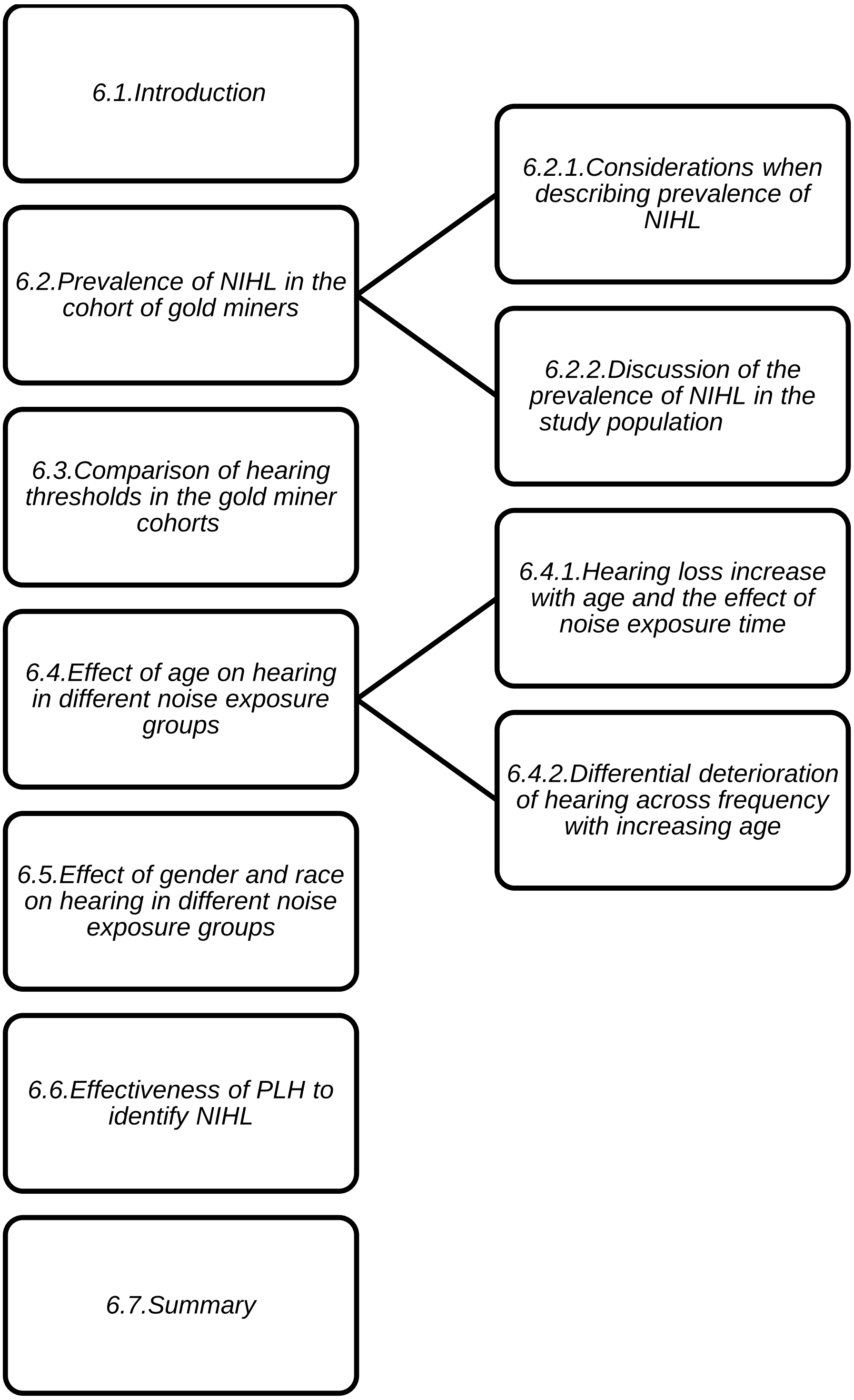
6. Discussion



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.

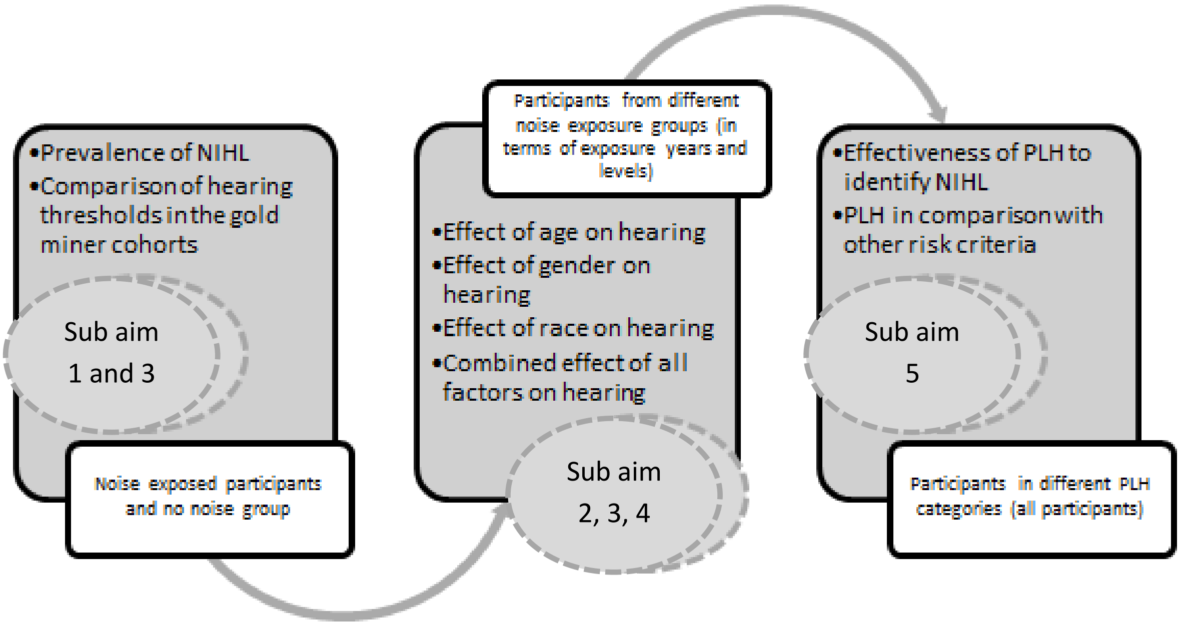


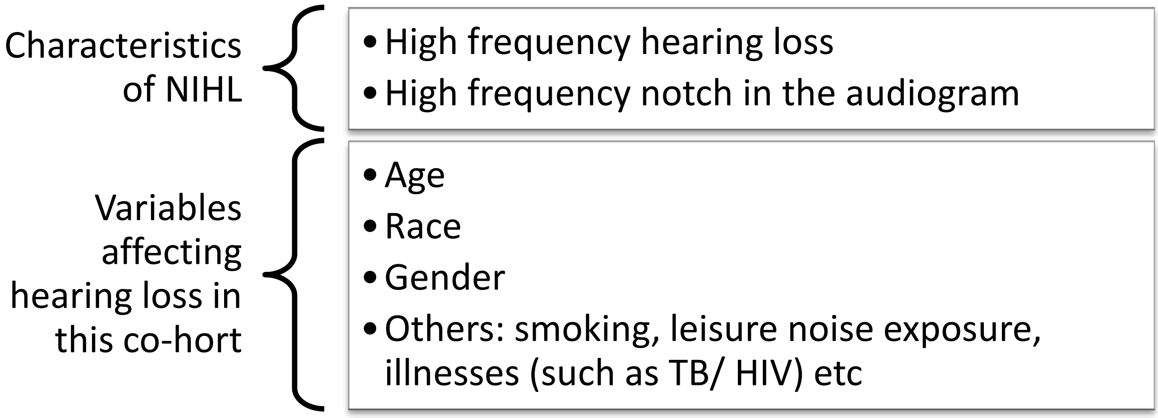
Figure 6-1 Framework for discussion of study findings related to study aims

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.

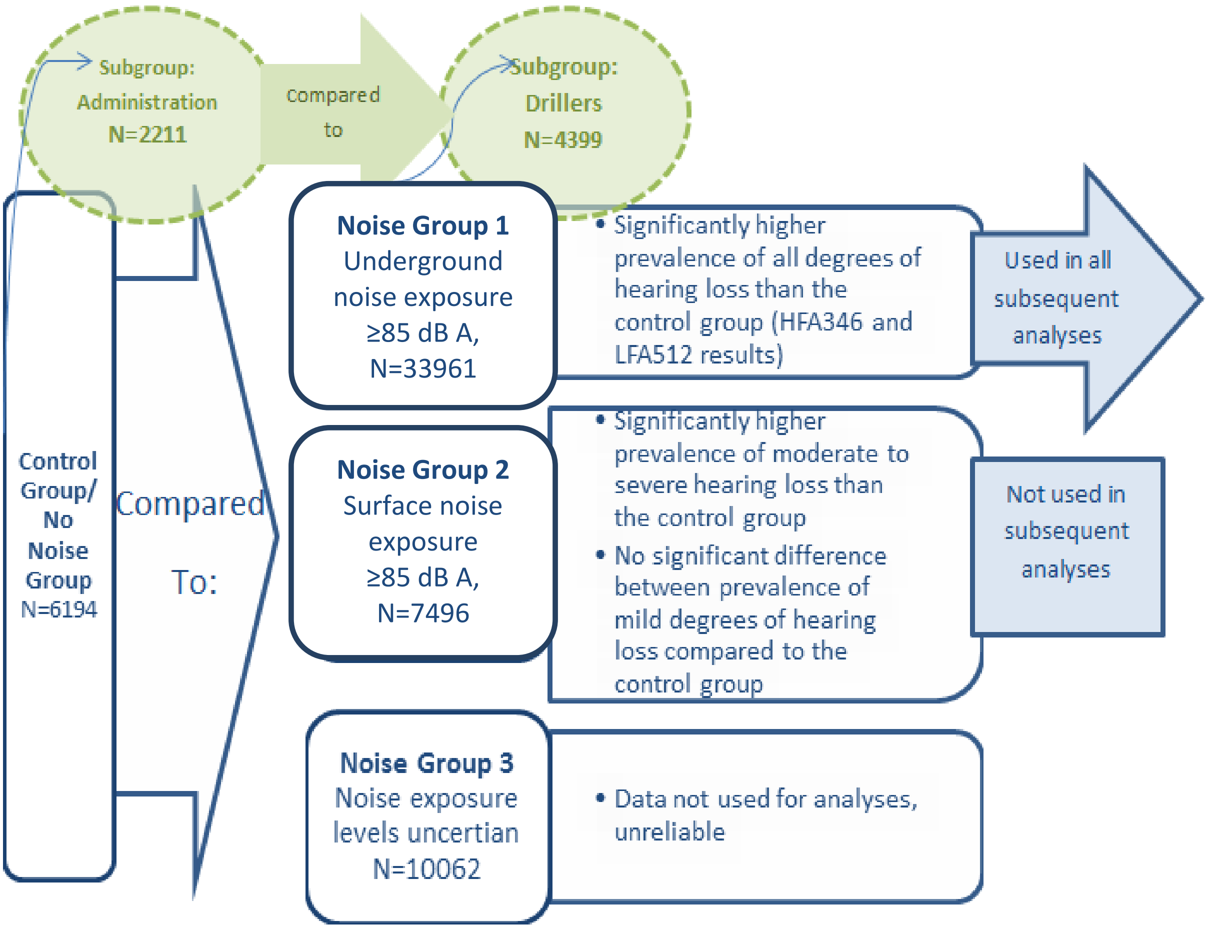


Figure 6-2 Different noise groups, and sub groups, the prevalence of NIHL compared to the control group and data used in analyses

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

[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.

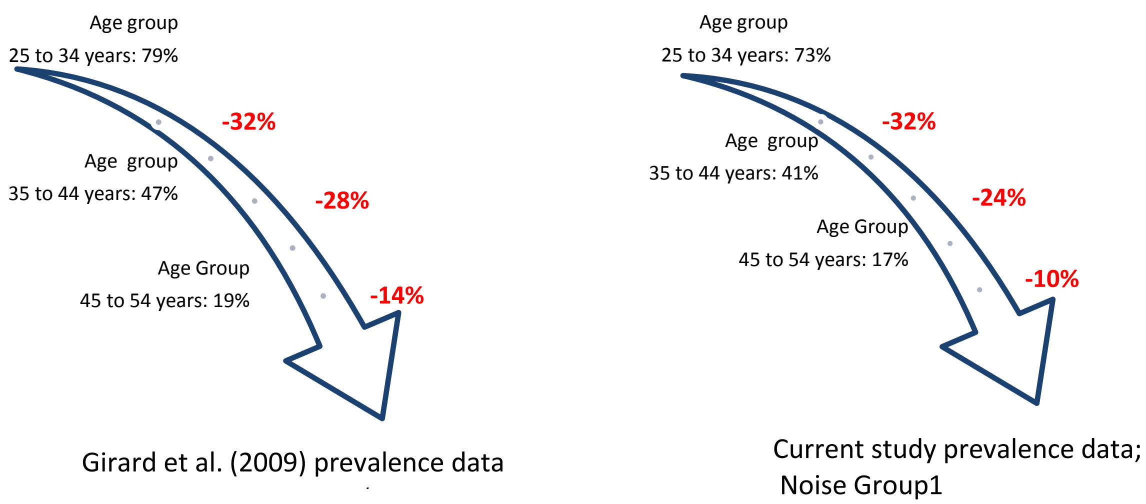


Figure 6-5 Comparison between Girard et al. (2009) and the current study's negative growth in prevalence of the normal hearing category with increase in age (shown as a difference in the percentage of participants with normal hearing between the subsequent age groups)

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

[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.