Chapter seven   CONCLUSION

7. Conclusion

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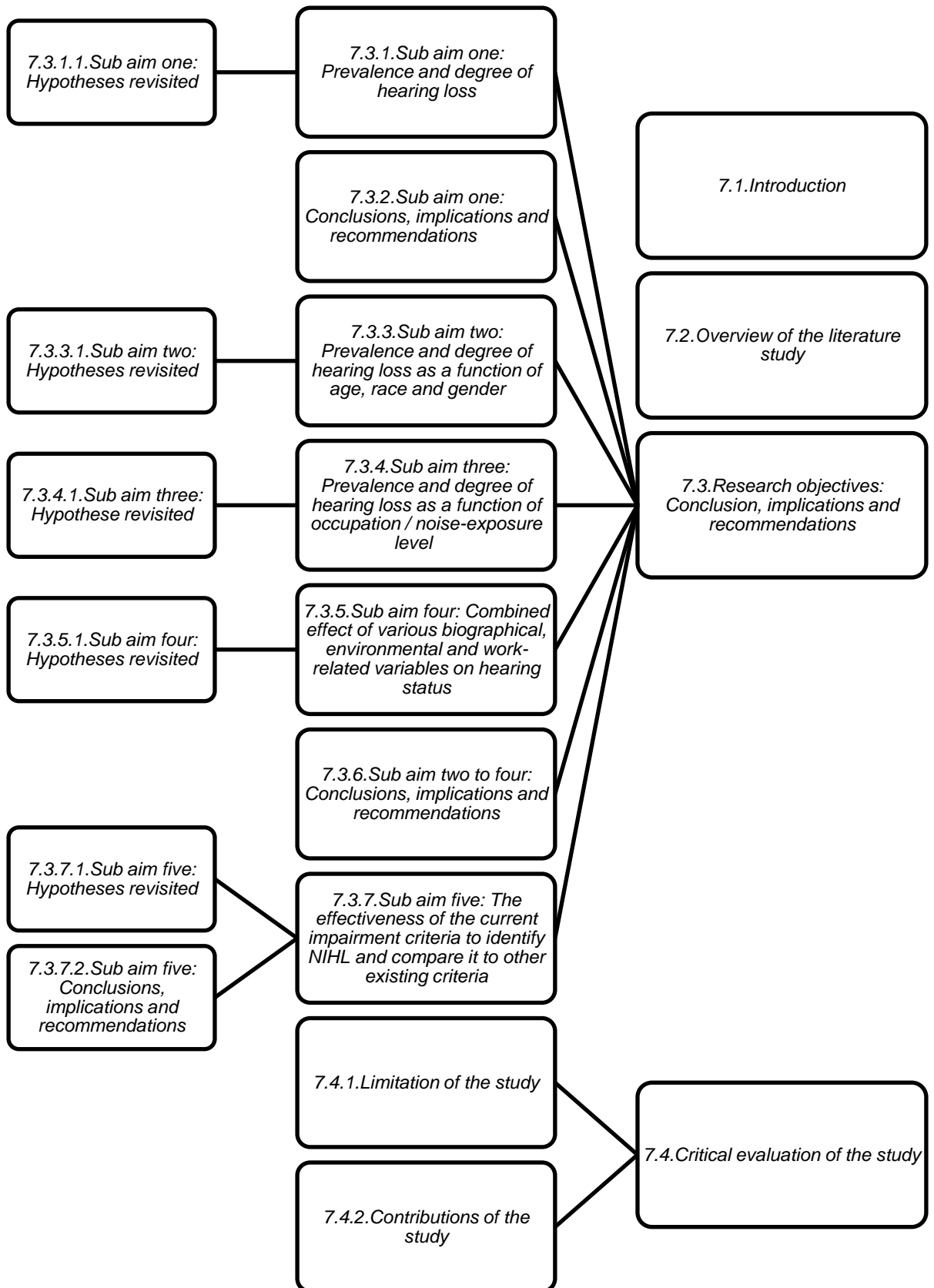
7.1. Introduction

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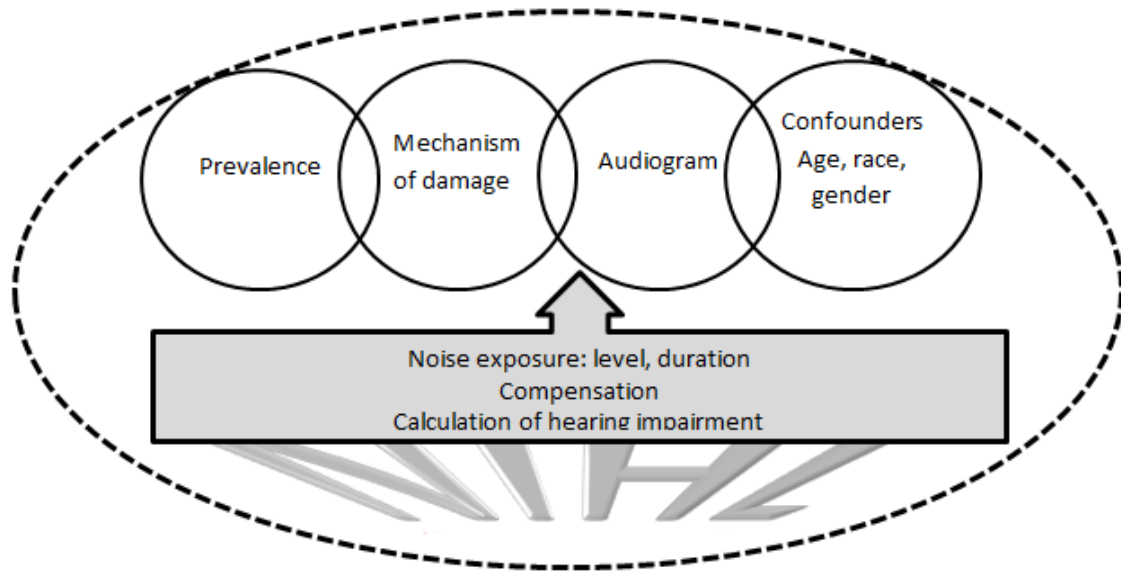
Figure 7-1 Main aspects reviewed in the literature study in Chapters 2 and 3

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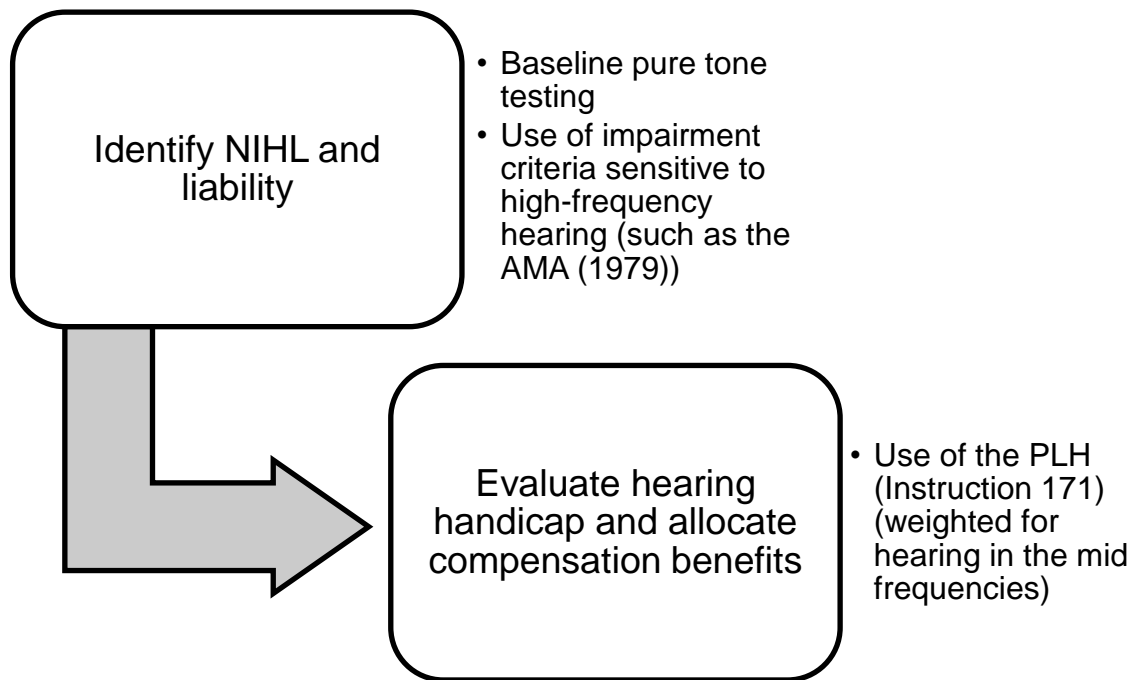
Figure 7-3 Two-step audiological process recommended for South African mines to identify NIHL and allocated compensation

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."