Prevalence and degree of noise-induced hearing loss in South African gold miners

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ABSTRACT
This study aimed to describe the prevalence of noise-induced hearing loss (NIHL) in a large group of gold miners (N=57 714). Noise exposure levels were used to categorise participants into different noise group categories and a control group. HFA346 and LFA512 (high and low frequency) averages were calculated from hearing thresholds and, where possible, analyses were adjusted for age.

The study found that exposure to occupational noise, despite hearing conservation programmes, was significantly associated with increased hearing thresholds. Results indicated that the noise-exposed groups had significantly higher prevalence rates of HFA346 and LFA512 hearing loss than the control group. The largest difference in prevalence of HFA346 hearing loss was observed for ages 36-45 years. HFA346 hearing loss was also observed in the control group. HFA346 hearing loss prevalence was affected by age, which should be taken into account when determining or predicting the effect of noise on hearing.

Keywords: **South Africa, NIHL, prevalence, occupational noise exposure, drillers, high frequency, low frequency**

INTRODUCTION
In South Africa, mining is the country's largest industry, employing 5.1% of all workers in the non-agricultural, formal sector of the economy, a reported total of 458 600 employees in 2006.[1] The processes associated with mining generate tremendous noise as a result of activities such as percussion drilling, blasting and crushing of ore, often exacerbated by confined and reflective spaces.[2]

The results of a recent study, investigating the profiles of noise exposure in South African mines, indicate that the mean noise exposure levels in the South African mining industry range from 63.9 to 113.5 dB A, and that approximately 73.2% of miners in the industry are exposed to noise levels above the legislated occupational exposure limit of 85 dB A.[3]

NIHL is preventable and the South African government mandates hearing conservation programmes. Still, a high prevalence of NIHL is reported. An audit of the Department of Mineral Resources in the RSA reported 1 820 cases of NIHL in 2007.[4] The Chamber of Mines reported a positive downward trend in the number of NIHL cases since the baseline in 2002/2003 (a rate of 15 per 1000 workers was reported then); the current rate of NIHL is 3.1 cases per 1 000 employees.[5] It is possible that reported NIHL cases could have been inflated soon after 2001 as baseline hearing testing was only mandated after 2001 when Circular Instruction 171 was issued under the Compensation for Occupational Injuries and Diseases Act (No. 130 of 1993).[6]

In 2005, the Mine Health and Safety Council (MHSC), comprising representatives of state, labour and employers, signed an agreement with the mining industry to achieve two important milestones, namely, no deterioration in hearing greater than 10% amongst occupationally exposed individuals after December 2008, and the total noise emitted by any equipment to not exceed 110 dB A at any location in that workplace, by December 2013. As a consequence, the MHSC (2006)[2] recommended the calculation of reliable prevalence data on NIHL as a focus area within occupational health research.

Apart from annual reports available from specific mining groups, the MHSC and the Chamber of Mines, limited data exist on the prevalence and incidence of NIHL in the mining industry against which the MHSC target to reduce NIHL can be measured. Only one paper relating to prevalence of NIHL in underground mining in Africa, published in 1987, describes the hearing thresholds of a group of white South African gold miners.[7] The current study aimed to describe the prevalence of NIHL in a large group of gold miners.

METHODOLOGY
An observational study design was followed. Approval

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was obtained from the relevant authorities responsible for research at the gold mine under investigation and the Ethics Committee of the University of Pretoria prior to the commencement of the study. Audiological data were accessed from the mine's electronic database (Everest) and all required information was exported into Microsoft Excel 2007 worksheets.

Data from the most recent audiograms of all mine employees, collected from 2001 to 2008, were included (N= 57 714). Noise exposure levels were described in terms of a specific occupation and categorised into three groups based on dosimeter data received from the mine's noise hygienist, namely: 1) below surface (underground) noise exposure, ≥85 dB A, classified according to the South African regulations on the daily permissible dose of noise exposure[8], named Noise Group 1; 2) surface noise exposure, ≥85 dB A, named Noise Group 2; and 3) no known occupational noise exposure, named control group. The control group was matched with participants of Noise Group 1 and 2 based on gender, race and age at the most recent audiogram test. There were 33 749 participants in Noise Group 1, 7 456 in Noise Group 2, and 6 162 in the control group.

To investigate the effect of noise exposure on the hearing of miners, a subgroup of drillers was identified within Noise Group 1 and a subgroup of administrative workers was identified from the control group. South African gold mines define homogenous exposure groups (HEGs) as groups of workers where occupational noise exposure, in terms of duration and intensity, is the same. Drillers in South African gold mines are typically exposed to occupational mean noise levels of 105.5 dB A.[3] The administration group comprised administrative workers who had not previously been exposed to occupational noise. This latter group was matched with the driller subgroup by age, race and gender.

Hearing thresholds were classified into categories based on degree of impairment as proposed by Yantis[9] and used by Picard et al.[10] and Girard et al.[11] NIHL was defined as a bilateral high frequency hearing loss.[10] Based on the data from this large-scale study (N=53 000) by Girard et al.,[11] we suggest that, within the context of NIHL, Yantis' low fence at 16 dB HL appears to be a functional cut-off point to decide on the presence of some minimal degree of hearing loss.

The bilateral high frequency hearing loss was operationally defined as the bilateral average value of 3, 4 and 6 kHz (HFA346); the low frequency average (LFA512) was calculated using the average of 0.5, 1 and 2 kHz. To avoid any confounding influence of age in comparisons, 'age at test' was adjusted for during analyses using ANCOVA, a procedure for comparing mean values of research variables while controlling for the influence of a continuous variable (covariate), such as age. Pairwise tests on observed differences between groups were conducted using the Fisher's least square's differences approach. In order to compare the prevalence of hearing loss across the different study groups, 95% confidence intervals (CIs) for the different proportions in each hearing sensitivity category were calculated. The 95% CIs for the differences between two proportions were determined using the normal approximation for the binomial distribution.

RESULTS

Table 1 shows that the control group had the highest proportion of participants in the normal hearing category (HFA346 and LFA512 results). Noise Group 1 had the highest

Table 1. Distribution of workers according to hearing sensitivity and noise exposure categories (N_{0-15} + N_{15-30} +N_{31-40} +N_{41-50} +N_{51+}=N_1/ N_3/ N_2)

Category of hearing sensitivity (dB)*	Noise exposure category					
Bilateral HFA346 (3, 4, 6 kHz)	Noise Group 1 ≥85 dB A N_1= 33 749		Noise Group 2 ≥85 dB A N_2= 7 456		Control Group <85 dB A N_3= 6 162	
Normal hearing 0-15 dB	N_{0-15} 15 388	% 45.5	N_{0-15} 3 668	% 49.1	N_{0-15} 3 297	% 53.5
Just noticeable HL 16-30 dB	N_{15-30} 11 389	33.7	N_{15-30} 2 329	31.2	N_{15-30} 1 871	30.3
Mild HL 31-40 dB	N_{31-40} 3 153	9.3	N_{31-40} 660	8.8	N_{31-40} 498	8.2
Moderate HL 41-50 dB	N_{41-50} 1 817	5.3	N_{41-50} 396	5.3	N_{41-50} 249	4.1
Severe HL 51+ dB	N_{51+} 2 002	5.9	N_{51+} 403	5.4	N_{51+} 247	4.0
Bilateral LFA512 (0.5, 1, 2 kHz)	Noise Group 1 ≥85 dB A N_1= 33 749		Noise Group 2 ≥85 dB A N_2= 7 456		Control Group <85 dB A N_3= 6 162	
Normal hearing 0-15 dB	N_{0-15} 25 934	% 76.8	N_{0-15} 5 807	% 77.9	N_{0-15} 4 992	% 81.0
Just noticeable HL 16-30 dB	N_{15-30} 5 687	16.9	N_{15-30} 1 228	16.5	N_{15-30} 903	14.7
Mild HL 31-40 dB	N_{31-40} 1 199	3.6	N_{31-40} 236	3.2	N_{31-40} 172	2.8
Moderate HL 41-50 dB	N_{41-50} 463	1.4	N_{41-50} 107	1.4	N_{41-50} 59	1.0
Severe HL 51+dB	N_{51+} 466	1.4	N_{51+} 78	1.0	N_{51+} 36	0.6

*hearing loss (HL)

proportion of participants (6%) in the HFA346 severe hearing loss category. Noise Group 1 had a significantly higher prevalence of hearing loss of all degrees than the control group (95% CIs: just noticeable hearing loss (HL) category 0.02;0.05, mild HL category 0.0;0.02, moderate HL category 0.01;0.02, and severe HL category 0.01; 0.02). The proportion of controls with normal hearing was significantly greater than that of the Noise Group 1 miners (95% CI: 0.91;0.64). This was also true for the LFA512 hearing loss results. For both high and low frequency averages (HFA346 and LFA512), the control group had a significantly greater proportion of participants in the normal hearing group than did Noise Group 2 (95% CI: 0.06;0.03). Noise Group 2 had a significantly greater proportion of participants than the control group in the following instances: HFA346 results for the moderate and severe hearing loss groups (95% CI: 0.01;0.02), and LFA512 results for the just noticeable (95% CI: 0.01;0.30), moderate (95% CI: 0.00;0.01), and severe hearing loss groups (95% CI: 0.01;0.01).

Because of the significant differences in all categories observed between Noise Group 1 and the control group participants, further analyses of these two groups were performed, taking into account the effect of age. The results are shown in Table 2. LFA512 results are not shown but, in an analysis of covariance (ANCOVA), Noise Group 1 and the control group differed significantly with respect to mean LFA512 (p=0.00) and mean HFA346 (p=0.01) (Noise Group 1 showed more elevated mean HFA346 values than the control group). Note that the number of participants in this analysis differed slightly from the total as some data were lost because only participants younger than 25 years and older than 65 years were included in the age-adjusted analysis.

Table 2 shows that the prevalence of hearing loss greater than 30 dB in both the noise exposed and control groups was high. The largest difference in the proportion of participants with HFA346 (high frequency) hearing loss was observed in the age group 36-45 years. In this age category 14% of the participants in the control group had HFA346 hearing loss of more than 30 dB compared to 18% in Noise Group 1. In the older age groups, the difference in prevalence of hearing loss of more than 30 dB was less than 2% between the control and noise exposed group. For age groups 46-54 and 56-65 years, Noise Group 1 had a prevalence of 39.3% and 62.7%, respectively.

To understand the changes of hearing in noise-exposed aged workers, participants were divided into the different age groups and then further divided into the number of years that they had been working. In all age groups, participants with more years of exposure to noise presented with worse hearing across the frequency range than those with fewer years of noise exposure. In all the age groups, changes in thresholds with more working years were small when comparing working years in five-year increments. Changes become more pronounced after 10 years of noise exposure (5 – 15 working years).

Participants in noise Group 1 also had lower median hearing sensitivities at all frequencies than those in the control group after adjusting for age: 0.5 kHz, p=0.00; 1 kHz, p=0.00; 2 kHz, p=0.00; 3 kHz, p=0.00; 4 kHz, p=0.00; 6 kHz, p=0.00; 8 kHz, p=0.00. Based on the notch criteria of Coles et al. (2000),[13] defined as a high-frequency notch where the hearing threshold at 3, 4, and/or 6 kHz is at least 10 dB greater than at 1or 2 kHz and at least 10 dB greater than at 6 or 8 kHz, a notch was observed in all groups at 6 kHz (10 dB notch). This notch should be interpreted with caution as it could be attributed to a calibration error when using TDH-39 headphones as has been described in the literature.[14]

As exposure levels differed between the participants within the broader noise groups (Noise Group 1 and the control group), participants were divided into HEGs. Two groups were selected for comparison, viz. drillers from Noise Group 1 (noise exposure ≥90 dB A) and an administration group from the main control group (to serve as a control group for the driller group).

From Figure 1 it is clear that the median as well as the 95th percentile values of hearing thresholds across the hearing frequency spectrum were very different for the driller and administration groups. All values for the drillers were markedly more elevated than those for the administration group. In the frequency range of 3 – 8 kHz, median hearing thresholds for the drillers were 10 dB higher than those for the administration group; 95th percentile values for drillers ranged from 45 – 75 dB HL compared to 30 – 60 dB HL for the administration group. Across the frequency spectrum, drillers' 95th percentile thresholds were approximately 20 dB higher than those of the administration group. After adjusting for age, the drillers had significantly greater mean HFA346 and LFA512 hearing loss (p=0.00 and p=0.07, respectively).

DISCUSSION

We found that exposure to occupational noise, despite prescribed personal hearing protection, was significantly associated with increased hearing thresholds. These findings are in agreement with previous international reports.[15-20] Significantly more participants in the noise groups than the control group presented with all degrees of hearing loss (both HFA346 and LFA512). The greatest difference in prevalence of HFA346 hearing loss was observed between the groups in the 36 – 45 year age category.

The prevalence of hearing loss was associated with increasing age. The relative contributions of noise and ageing to the progression of hearing loss are complex.[17,21,22] The deceleration of NIHL displayed by the noticeable effect of NIHL in the younger age groups and the reduced rate of change over time (with age) can be explained simply by considering that hair cells lost from one cause, such as noise damage, cannot be lost again from another cause, such as age.[22] Thus, one would expect less change over time in the thresholds of the frequency areas in the cochlea damaged by noise.[23] According to Nelson et al. (2005),[18,19] the fraction of hearing loss that can be attributed to occupational noise decreases as a person grows older.

Comparisons of findings with those from other published studies 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. Only a few large-scale comparable prevalence studies have been published. Picard et al. investigated the relationship between noise exposure levels in the workplace, degree of hearing loss, and the relative risk of accidents.[10,11] Their 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. Prevalence data of hearing loss in these occupational noise-exposed participants were published in the different age and hearing loss groups. The noise-exposed participants in our study had a lower prevalence of hearing loss greater than 30 dB in all age categories than those in the study by Girard et al.[11] For hearing loss of more than 30 dB, prevalence values from

Table 2. Distribution of workers according to hearing sensitivity (bilateral HFA346) and noise-exposure levels categories, and ISO 1990:1999[12] age groups

Category of hearing sensitivity (dB)* Age group (ISO 1990:1999)	Noise exposure category			
Bilateral HFA346	Noise Group 1 ≥85 dB A Total=31 105		Control Group <85 dB A Total=5 668	
Age 25-35 years	N=8 934	%	N=2 096	%
Normal hearing 0-15 dB	6 557	73.4	1 553	74.1
Just noticeable HL 16-30 dB	1 978	22.1	452	21.6
Mild HL 31-40 dB	226	2.5	59	2.8
Moderate HL 41-50 dB	112	1.3	12	0.6
Severe HL 51+dB	61	0.7	20	1.0
Age 36-45 years	N=12 303	%	N=2 158	%
Normal hearing 0-15 dB	4 998	40.6	1 074	49.8
Just noticeable HL 16-30 dB	5 100	41.5	775	35.9
Mild HL 31-40 dB	1 189	9.7	175	8.0
Moderate HL 41-50 dB	516	4.2	72	3.3
Severe HL 51+dB	500	4.1	62	2.9
Age 46-54 years	N=8 087	%	N=1 196	%
Normal hearing 0-15 dB	1 415	17.5	228	19.1
Just noticeable HL 16-30 dB	3 493	43.2	523	43.7
Mild HL 31-40 dB	1 378	17.0	203	17.0
Moderate HL 41-50 dB	884	10.9	134	11.2
Severe HL 51+dB	917	11.3	108	9.0
Age 56-65 years	N=1 781	%	N=218	%
Normal hearing 0-15 dB	131	7.4	12	5.5
Just noticeable HL 16-30 dB	533	29.9	70	32.1
Mild HL 31-40 dB	320	18.0	53	24.3
Moderate HL 41-50 dB	295	16.6	27	12.4
Severe HL 51+dB	502	28.2	56	25.7

*hearing loss (HL)

the study by Girard et al. were higher than this study for all age groups. It is possible that the differences might be a result of different noise levels experienced by participants in the two studies (participants of Noise Group 1 included workers with noise exposure of >85 dB A compared to the >90 dB A noise level for the Girard et al. study). The difference might also be explained by the differences in demography. The participants of the study by Girard et al. were mostly white men, while 85% of participants in Noise Group 1 were black men. Results from 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.[15,24,25] Nevertheless, a non-linear decline in hearing with age was demonstrated in both of these large studies, regardless of race and noise-exposure differences, as shown in Figure 2.

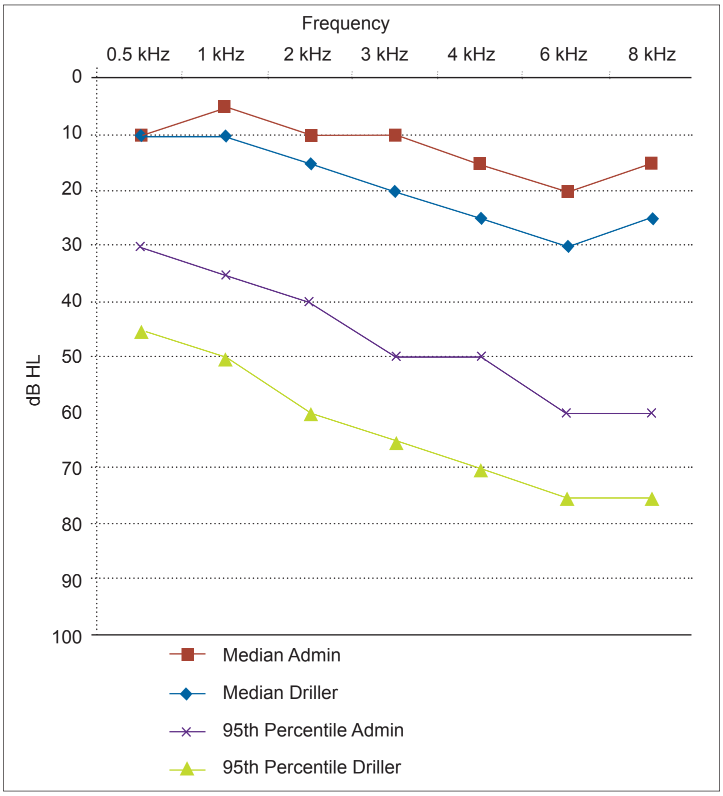

Figure 1. Median and 95th percentile values for thresholds (in dB HL) across the frequency range for drillers and the administration group

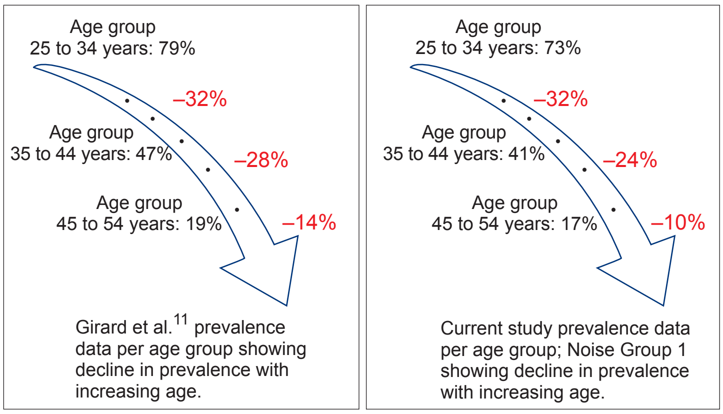

Figure 2. Comparison between Girard et al.[11] and the current study's negative change in prevalence of the normal hearing category with increase in age (shown as a difference in the percentage of participants with normal hearing between age groups)

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, the control group also experienced HFA346 hearing loss, across all age groups. For example, 16% of the control group had a hearing loss greater than 30 dB compared to 20% in Noise Group 1. Comparison of these results with a longitudinal, population-based study of adults aged 48 – 92 years at baseline examination conducted in the Beaver Dam Community Hospital in Wisconsin (USA)[26] shows that the prevalence of hearing loss in the control group of this study was considerably higher than that in the Beaver Dam study participants. For example, the incidence of hearing loss greater than 25 dB in the Beaver Dam study participants aged 48 – 59 years was 7%, compared to 37% hearing loss greater than 30 dB in our control group, aged 46–54 years.

It is possible that the control group might have included persons with some previous exposure to occupational noise since information on the work history of participants was not available. Exposure to noise sources other than occupational noise should also be considered in the control group. For example, 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.[27]

It is possible that non-occupational noise exposure could exacerbate or cause NIHL in both 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%)[28] might be contributing to hearing loss in both the noise-exposed and control groups. In a recent study, a significant degree of high frequency sensorineural hearing loss was observed in HIV patients.[29] Because of mine policy regarding consent and confidentiality of HIV test results, it was not possible to obtain information about the HIV status of the study population.

Another factor that might predispose individuals to permanent hearing loss, especially those exposed to occupational noise, is tuberculosis and its associated risk profile.[30,31] A study of the effect of tuberculosis on the hearing status of gold miners concluded that a significant relationship between tuberculosis and deterioration in hearing thresholds exists.[30] In the current study, 4.7% of the 57 714 miners were diagnosed with tuberculosis. This relatively small percentage of tuberculosis-infected workers was represented in all noise-exposed groups and the control group. Further investigation into the causes of hearing loss in the control group is suggested as a follow-up study.

CONCLUSION AND RECOMMENDATIONS

Although the lower prevalence of high frequency hearing loss compared to other studies, and the relatively small difference in the prevalence of hearing loss between the noise-exposed and control groups could suggest that conservation programmes are effective, comparison of baseline audiograms with more recent audiograms would provide a more direct measure of hearing conservation effectiveness. A limitation of this study was that audiograms for all participants were not available at consistent intervals from baseline testing.

Other medical factors, such as tuberculosis or HIV could have contributed to the hearing loss in the control group. It is also possible that other noise sources could have contributed to hearing loss in the control groups. Hearing loss in noise-exposed gold miners was, however, more prevalent than in the control group, especially in the age group 36 – 45 years of age. Participants from occupational groups with higher levels of noise exposure (drillers) had higher median thresholds values than the median threshold values of the underground mine workers.

Hearing conservation programmes should be evaluated and refined in order to reach the MHSC milestone relating to NIHL. Results have shown that prevalence of HFA346 hearing loss is affected by the age of participants. 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.

LESSONS LEARNED

- NIHL is more prevalent in the noise-exposed than the unexposed control group, especially in the group aged 36 – 45 years.
- Miners with higher levels of noise exposure (drillers) showed higher hearing thresholds than underground miners, in general, who are exposed to more than >85 dB A.
- Age is an important risk factor for high frequency hearing loss.
- Hearing loss prevalence was high in the control group and should be investigated further to explore contributing factors, such as occupational and non-occupational noise-exposure, tuberculosis and HIV infection, and treatment, etc.

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