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Occupational noise-induced hearing loss: What is the contribution of personal noise exposures? A case study of mineworkers at a large-scale platinum mine in South Africa

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Abstract

Background: South African mineworkers are exposed to excessive noise which leads to occupational noise-induced hearing loss (ONIHL). However, there is a dearth of literature on the contribution of personal noise exposure measurements to predict the development of ONIHL. **Aim:** We aimed to determine the predictive ability of age, sex, personal noise measurements, and work shift duration as early signs of hearing deterioration associated with ONIHL for mineworkers at a large-scale platinum mine in South Africa. **Methods:** Two merged electronic datasets, comprising records of 521 mineworkers, were analysed, viz. a dataset of personal noise exposure measurements and an audiometry screening dataset, for the period 2014 to 2018. Pearson Chi^2 test described the associations between personal noise measurements, age, sex and shift duration, and hearing deterioration (STS). LOWESS assessed the correlation between personal and area noise measurements and hearing deterioration and personal noise measurements. Multinomial logistic regression analysis was used to identify risk for ONIHL, classified as mild, moderate, moderate-severe and profound hearing loss. **Results:** Most of the mineworkers were male (n = 480; 92.1%), aged 26-55 years (n = 452; 86.6%), and most were exposed to personal noise measurements less than 85 dB(A) (n = 303; 61.1%). Pearson Chi^2 indicated age as a significant risk factor associated with STS. LOWESS indicated a positive association between personal and area noise measurements, but no association between personal noise measurements and STS. Multinomial logistic regression showed age as a significant risk for STS, mostly for mineworkers with STSs at mild, moderate and moderate-severe hearing loss in both ears. **Conclusion:** Mineworkers' age was associated with STSs and was a risk factor that had a significant predictive ability for ONIHL. We highlighted the usefulness of personal noise measurements as risk-based assessment tools for audiometry surveillance that the South African mines could use to evaluate noise reduction strategies and outcomes for ONIHL prevention.

Keywords

personal noise measurements, occupational hearing loss, work shift, mineworkers, audiometry, age-related hearing loss

Introduction

It is well documented that occupational noise exposure ≥85 dB(A) leads to occupational noise-induced hearing loss (ONIHL).[1] This finding has also been reported in the mining industry in South Africa and other countries[2,3] where prevalences of ONIHL are reported to range from 7% to 21%.[4] The estimated prevalence of ONIHL in the mining industry in African countries is higher (11% - 37%) than in countries in the global North where reported rates range from 10% to 24%.[2,4] Occupational noise-induced hearing loss is common in South Africa across all mining commodities. The Mine Health and Safety Council (MHSC) milestone to eliminate ONIHL is based on quietening equipment that emits high noise and reducing the total occupational noise exposure levels to ≤107 dB(A) by December 2024.[5] Profiling noise exposures and tracking ONIHL prevalence rates is imperative for mines in South Africa to monitor progress towards meeting these targets.

Measuring personal noise exposures, using a dosimeter, is the preferred method for accurately assessing mineworkers' exposure to noise associated with ONIHL.[3,6] A

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dosimeter is a device fitted on the individual's upper body, with a microphone placed on the shoulder, close to the ear.[7] Although most South African mines have implemented personal sampling strategies for measuring noise exposure, information about the strategies that they use to determine the contribution of noise exposure to ONIHL is sparse.

Factors other than exposure to occupational noise that are associated with an increased risk of hearing loss are socio-demographic factors (age, sex and race), genetic predisposition, recreational noise, and other occupational exposures (mine dust and chemicals).[3,8–11] Research in South Africa has shown that ototoxic drugs used for the treatment of pulmonary tuberculosis (PTB) and human immunodeficiency virus (HIV) infection also increase the risk of NIHL in mineworkers.[9,12] While occupational noise exposure intensity and duration remain the main risk factors for hearing impairment in South African mineworkers, other exposures such as recreational noise, have not been acknowledged as additional risks. Therefore, comprehensive audiometry testing that considers all these risk factors is imperative.[3,6,13]

To accurately assess mineworkers' hearing function, in 2017, the South African mines adopted the Noise-Induced Hearing Loss Regulations to include the calculation of standard hearing threshold shifts (STS) when assessing mineworkers' hearing function and to track early signs of hearing loss associated with noise exposure.[14] The STS method is based on the International Organization for Standardization (ISO) standard 1999:2013 (ISO1999: 2013), which specifies that a decline of 8 dB in the STS from baseline indicates early ONIHL.[15,16] The US National Institute for Occupational Safety and Health (NIOSH) defines an STS as a shift of 10 dB from baseline.[16] The South African mines use the STS method to track workers' hearing sensitivity to prevent hearing loss and to benchmark mineworkers' hearing function.[14] The industry further resolved that, by December 2024, no employee's STS should exceed 10 dBHL from baseline when averaged at 2000, 3000 and 4000 Hz in one or both ears.[5] Globally, although there is variation in monitoring hearing deterioration for workers exposed to excessive noise levels, there is agreement that their hearing should be regularly monitored to ensure that it does not deteriorate further.

To reduce occupational noise exposure levels and eliminate ONIHL, the South African mines use risk assessment tools that are based on the South African Mining Industry Code of Practice (CoP).[17] Noise risk assessment involves the measurement of personal noise exposure levels and the identification of homogenous exposure groups (HEGs) at risk of developing ONIHL. The CoP describes a HEG as a group of employees with similar exposures to an identified hazard (e.g. noise).[17] This similarity allows for a representative sample of workers at risk of exposure to be selected for assessment to estimate the exposure levels of the entire workforce. The sample size for each HEG is determined as either five or 5% of the total number of workers in the HEG, whichever number is larger. The classification category of exposure is risk-ranked, and this determines the frequency of sampling.[7,17] However, concerns have been raised, regarding the variability of HEGs and, consequently, the reduced effectiveness of risk assessment tools used to track mineworkers' hearing function.[18,19] Thus, research is needed to investigate and mitigate risks associated with ONIHL.

The purpose of this study was to assess the association of age, sex, personal noise measurements, and duration of daily work shifts with early signs of hearing deterioration (STS) associated with ONIHL for mineworkers at a large-scale platinum mine in South Africa.

Methods

Study design and data collection

We conducted a cross-sectional analysis of retrospective data from two datasets, containing records of underground mineworkers employed by a platinum mine in Limpopo province, South Africa. The two datasets comprised records of hearing screening and occupational noise measurements for the period 2014–2018. and included demographic data, area noise exposure measurements, personal noise measurements, and calculated STS values. The 648 records represented 5% of the mine's population that was exposed to 5% of the individual pieces of equipment that emitted excessive noise, as per the Mine Health and Safety Act.[7,20,21]

The hearing screening dataset contained bilateral hearing screening records for individual mineworkers, from 2014 to 2018. Regardless of when a mineworker was initially employed at the mine, we used the 2014 - 2016 hearing thresholds as the baseline values; the 2018 hearing thresholds were used to calculate changes from baseline for each mineworker.[14] The records were accessed from the audiometry medical examinations conducted by a qualified audiometrist (occupational health nurse) according to the South African National Standard (SANS) 10,083:2013.[7] This dataset contained hearing thresholds at the frequencies of 0.5, 1, 2, 3, 4, 6, and 8 kHz, for each ear and the ear-specific standard thresholds (ST) and calculated bilateral STS.[22]

The occupational noise dataset contained personal noise exposure measurements and area noise measurements. The personal noise exposure measurements for individual mineworkers were collected using noise dosimeters, positioned close to the ear, as a function of time, in 2018. The area noise measurements were collected using a sound level meter for various job areas. The data were captured in MS Excel by the mining company. All data were collected by qualified occupational hygienists and included mineworkers' age, sex, workplace area, HEG, job title, and work shift (hours) in 2018.

The two datasets, containing 648 mineworkers' records were merged in STATA (version 15.1), using the mineworker's assigned employee number, age, and sex. After removing duplicate and incomplete records, the merged

Table 1. Associations between variables and STS changes (left ear) $N = 521$.

					STS change (dBHL)								
	All		≤25 normal		26-45 mild		46–55 moderate		56–70 Moderately severe		71 + severe		
Characteristic	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*p* Value
Personal noise dB(A)													
≤81.99-84.99	313	60.1	260	49.9	38	7.3	7	1.3	4	0.8	4	0.6	0.910
≥85-105	208	39.9	176	33.8	27	5.2	4	0.8	1	0.2	0	0.0	
Age (years)													
≤25	3	0.6	3	0.6	0	0.0	0	0.0	0	0.0	0	0.0	0.000
26-40	209	40.1	203	39.9	3	0.6	0	0.0	2	0.4	1	0.2	
41-55	242	46.4	199	38.1	34	6.5	5	1.0	2	0.4	2	0.4	
56-65	67	12.9	31	6.0	28	5.4	6	1.2	1	0.2	1	0.2	
Sex													
Male	480	92.1	397	76.2	64	12.3	11	2.1	4	0.8	4	0.8	0.160
Female	41	7.9	39	7.5	1	0.2	0	0.0	1	0.2	0	0.0	
Shift (hours)													
≤8	76	14.6	66	12.7	8	1.5	1	0.2	0	0.0	1	0.2	0.764
>8	445	85.4	370	70.0	57	10.9	10	1.9	5	1.0	3	0.6	
Total	521	100	436	83.7	65	12.5	11	2.11	5	1.0	4	0.8	
Associations between variables and STS changes (Right ear)													
Personal noise exposure dB(A)													
≤81.99-84.99	313	60.1	266	51.1	32	6.1	8	1.5	5	1.0	2	0.4	0.834
≥85-105	208	39.9	174	33.4	28	5.4	4	0.8	1	0.2	1	0.2	
Age (years)													
≤25	3	0.6	3	0.6	0	0.0	0	0.0	0	0.0	0	0.0	0.000
26-40	209	40.1	201	38.6	6	1.2	1	0.2	1	0.2	0	0.0	
41-55	242	46.4	201	38.6	33	6.3	5	1.0	1	0.2	2	0.4	
56-65	67	12.9	35	6.7	21	4.0	6	1.2	4	0.8	1	0.2	
Sex													
Male	480	92.1	402	77.2	57	10.9	12	2.3	6	1.2	3	0.6	0.586
Female	41	7.9	38	7.3	3	0.6	0	0.0	0	0.0	0	0.0	
Shift duration (hours)													
≤8	76	14.6	65	12.8	8	1.5	3	0.6	0	0.0	0	0.0	0.615
>8.1	445	85.4	375	72.0	52	10.0	9	1.7	6	1.2	3	0.6	
Total	521	100	440	84.5	60	11.5	12	2.3	6	1.2	3	0.6	

Note: Data in Tables 1 (Left ear) and (Right ear) is ear specific.
Some mineworkers were exposed to high noise levels (≥85 dB(A), e.g. scraper winch operator ($n = 77$), mining team supervisor ($n = 32$) and cheesa ($n = 29$).

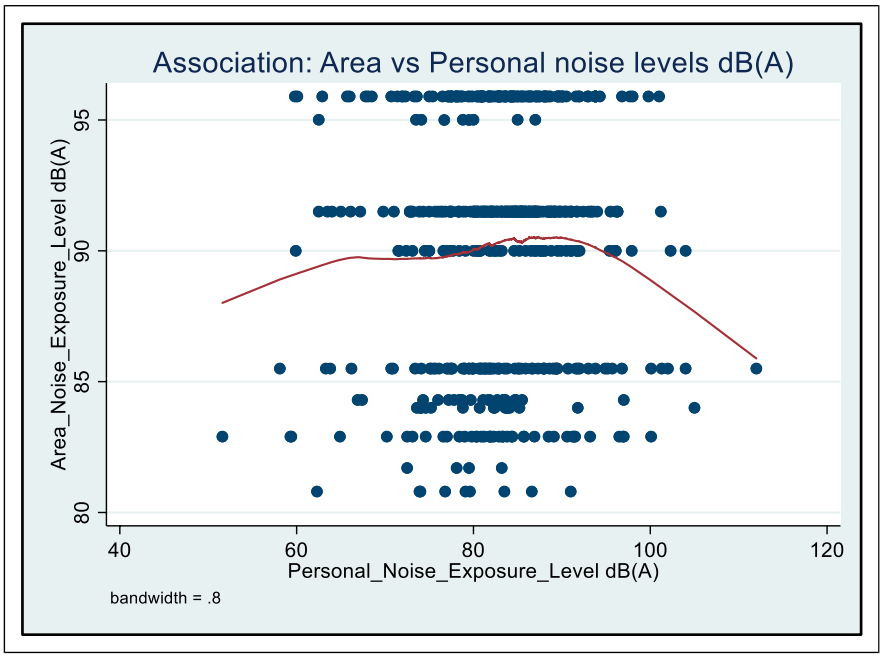


Figure 1. Association between personal and area noise measurements.

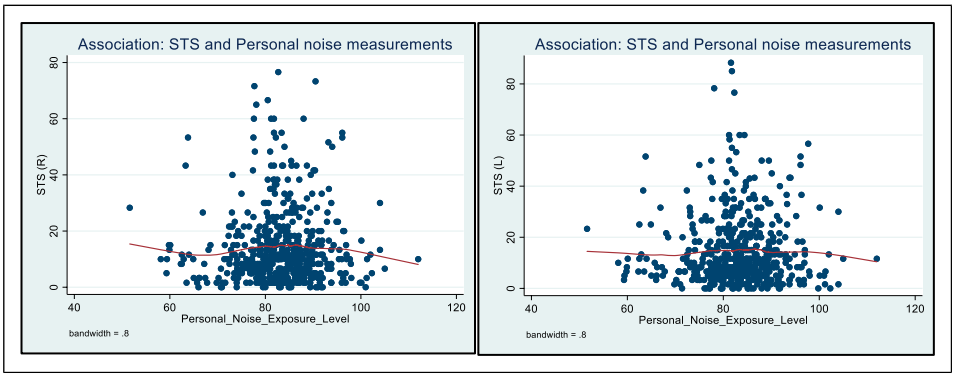


Figure 2. Association between personal noise levels and hearing function.

dataset contained 521 records. The data were categorised according to the miners' personal noise measurements and corresponding risk rankings, as follows: ≤81.99 dB(A) (Group 0), 82–84.99 dB(A) (Group 1), 85–104.99 dB(A) (Group 2), and ≥105 dB(A) (Group 3). Hearing function (as hearing sensitivity accessed from the audiometry screening dataset) was classified as within normal limits (-10 – 25 dBHL), mild hearing loss (26–45 dBHL), moderate hearing loss (46–55 dBHL), moderate-severe hearing loss (56–70 dBHL), severe hearing loss (71–90 dBHL), and profound hearing loss (>90 dBHL).[23]

Data analysis

The demographic, audiometry and work-specific characteristics of the mineworkers are summarised as numbers and frequencies (Table 1). Pearson Chi-square test was used to describe associations between personal noise measurements, age, sex and shift duration, and hearing deterioration (STS) in the left and right ears. Locally weighted scatterplot smoothing (LOWESS) was used to assess the relationships between personal and area noise measurements (Figure 1) and between personal noise exposure levels and hearing function (Figure 2). Multinomial logistic regression analysis was used to predict hearing deterioration, measured as STS (dependent variable), based on the mineworkers' age, personal noise measurements, and work shift duration (independent variables), which were selected as predictor variables. These predictor variables were also controlled for in the model. The risk ratios are reported with 95% confidence intervals. Statistical significance was set at 5% (p-value = .05).

Permission to use the mineworkers' data was granted by the mine management. Ethical clearance was obtained from

Table 2. Multinomial logistic regression model.

	*RRR		95% CI		*p* Value	
Hearing deterioration (STS)/Variables	Left ear	Right ear	Left ear	Right ear	Left ear	Right ear
Mild						
Age	6.734	4.412	4.180-10.849	2.818-6.907	<0.001	<0.001
Personal noise	1.156	1.319	0.841 -1.588	0. 959-1.814	0.370	0.088
Shift duration	1.063	0.910	0.449-2.514	0.393- 2.106	0.890	0.827
Moderate						
Age	10.213	6.754	3.442-30.296	2.576-17.707	<0.001	<0.001
Personal noise	0. 910	1.081	0. 458-1.807	0.564-2.073	0.788	0.813
Shift duration	1.508	0. 420	0.180-12.640	0.104-1.698	0.705	0.224
Moderate-severe						
Age	1.566	6.815	−0.874-1.835	1.705-27.236	0.487	0.007
Personal noise	0.756	0. 423	−1.225-0.779	0.125-1.427	0.587	0.166
Shift duration	0	0	0	0	0.979	0.987
Severe						
Age	2.386	5.047	0.528-10.770	0.844-30.182	0.258	0.076
Personal noise	0.315	1.087	0.056-1.774	0.312-3.786	0.191	0.895
Shift duration	0.628	0	0. 062-6.286	0	0.692	0.992

RRR: relative risk ratio Note: Sex is not considered a predictor variable.

the University of the Witwatersrand Human Research Ethics Committee (clearance certificate no. M180273).

Results

The findings reported are ear-specific, viz. left ear and right ear. We removed duplicate and incomplete records, and the final and merged dataset we describe in the study findings contained 521 records. Of the 521 mineworkers included in the analysis, most were males (n = 480; 92.1%), mostly their age ranged between 26 – 40 years and 41 – 55 years, n = 209 and n = 242 respectively (when combined n = 452; 86.6%), most worked shifts of more than 8 hours (n = 445; 85.4%) and most were exposed to personal noise measurements less than 85 dB(A) (n = 303; 61.1%). Most of the mineworkers presented with STS within normal hearing in both ears (n = 436; 83.7% left ear and n = 440; 84.5%). Mean STS ranged from 6 dBHL to 14 dBHL between 2014 and 2018, respectively, indicating a mean hearing deterioration of 8 dBHL from baseline. Table 1 illustrates a hearing deterioration from baseline, which was significantly associated with mineworkers' age.

Figure 1 shows a positive correlation between the personal and area noise measurements at levels below 85 dB(A). At noise measurements above 85 dB(A), there is a non-linear relationship between personal and area noise measurements.

Figure 2 illustrates no association between personal noise measurements and STS bilaterally. The flat smoothed line indicates that personal noise exposure levels may not accurately predict STS for this group of mineworkers.

The regression model corroborated the finding from the Chi-square analysis that age was a significant risk factor for hearing deterioration for mineworkers with STS at mild, moderate, and moderate-severe hearing thresholds (p < .001). Personal noise levels and shift duration were not significantly associated with hearing deterioration (Table 2).

Discussion

Risk-based audiometry assessment

Risk-based audiometry assessment in HCPs uses sampled records (5%) of integrated data from the personal noise measurements, audiometry and the HEGs (demographic and medical data) to identify risks associated with ONIHL.[7] Data used for the current study were aligned with the CoP that guides the risk-based audiometry assessment since mineworkers' personal noise measurements and audiometry screening datasets were used to predict risk for ONIHL. In addition, the two datasets used in our study consisted of the 5% sampled population accessed from the audiometry medical surveillance records of the mineworkers in line with the CoP for risk-based medical surveillance for HCPs to monitor mineworkers at risk of developing ONIHL.[17] Medical conditions of the mineworkers could not be accessed from the mine, thus, were not included in our study, and this is noted as a limitation. However, the findings from our study could be used by the study mine to benchmark their CoP for their HCPs and measurable outcomes towards the prevention of ONIHL.

Assessment outcomes of risk-based audiometry medical surveillance

Worldwide, outcomes for effective HCP include strategies used by the mines to reduce occupational noise exposure levels

to mitigate risk for ONIHL. From the data we analysed, personal and area noise measurements were used to describe noise exposure levels for the mineworkers in our study. Our findings indicated a positive association between the area and personal noise measurements at levels below 85 dB(A) and no association at high noise exposure levels (>85 dB(A)). Notably, for those mineworkers who were exposed to personal noise measurements higher than 85 dB(A), high noise exposure levels were attributed to localised sources of noise, rather than general area workspace occupational noise. This finding is imperative, indicating that the mineworkers' noise source (job-specific equipment used by the mineworker) was the main contributor, and movements between various job activities contributed to higher personal noise measurements. Our study findings indicated targeted noise sources and were in agreement with the MHSC strategy of quietening specific equipment that emits high noise exposure levels to meet their noise reduction target by December 2024.[5] However, it must be noted that profiling noise exposure levels using dosimeters was restricted to only five percent (5%) of the mineworkers who were profiled as at risk and were identified according to their HEGs by the occupational hygienist. Therefore, accurate recording of personal noise measurements may be used as a context-specific risk-based assessment strategy by the South African mines. In addition, personal noise measurements should be used to track progress made regarding buying quiet equipment, in turn, showing progress made towards reducing occupational noise exposure levels.

Profiling of mineworkers at risk for ONIHL includes monitoring noise exposure levels and tracking hearing function using STS, to monitor progress made by the South African mines towards meeting the set NIHL milestone targets.[14] Firstly, most of the mineworkers in our study presented with STS within normal hearing (≤25 dBHL) in both ears. While the STS may fall within normal hearing limits, it is important to note that a mean shift of 8 dBHL was reported in our findings. A similar finding was reported by Ntlhakana et al. (2021). Although this shift was less than 10 dBHL, which is a recommended reportable shift according to the NIHL Regulations, any shift, however small, should still be reported for monitoring purposes.[14] Therefore, we posit that the STSs within normal hearing limits do not imply a no shift but rather a risk-based surveillance marker for early intervention. In addition, a shift may not meet the threshold for clinical or regulatory significance, but in the case of the South African mineworkers who are at risk of exposure to high levels of occupational noise, any shift should be documented accordingly. Secondly, our findings indicated that personal noise exposure measurements were not a significant predictor of STS for the mineworkers. This holds true since most of the sampled mineworkers were exposed to noise levels that were less than 85 dB(A). Ideally, similar findings would be reported in contexts where an effective HCP is in place, particularly through consistent use of PPE, engineering and administrative controls which reduce noise levels below 85 dB(A), but this was contrary to previous study findings in the South African mines.[3,6,13] However, age was found to be significantly associated with the mineworkers' STS, this finding correlates with Grobler et al. (2020) and Strauss et al. (2014) but contradicts Ntlhakana et al. (2021). The fact that the current study used personal noise measurements as opposed to area noise measurements meant that differences in findings should be noted. Specific to our case, mineworkers' changes in hearing thresholds were mostly associated with age and not necessarily occupational noise exposure levels.[2,19] Profiling of mineworkers using personal noise measurements to determine risks for ONIHL was imperative. Without minimising hearing health risks associated with noise exposure levels, especially in a South African context, our case study highlighted that mineworkers' age was a significant risk factor for ONIHL. Thus, in the absence of personal noise exposure measurements, mineworkers' age should be used as an outcome measure for ONIHL.

A clearly defined audiometry surveillance protocol intended as a risk assessment tool for the South African mines could be a useful measure to accurately track the hearing function of mineworkers and to identify early those at risk for ONIHL. Our study showed that the mine conducted a risk-based audiometry surveillance, using personal noise measurements on a sample of mineworkers. The regression model we used revealed that the sampled mineworkers' age was significantly associated with hearing deterioration for mineworkers with STS at mild, moderate, and moderate-severe hearing thresholds. The current study findings were in agreement with the study we conducted previously, which predicted STS, that age was a significant risk factor associated with hearing deterioration.[15,19] However, the frequency range selected to calculate the STS was 2000 Hz, 3000 Hz and 4000 Hz, as outlined in the revised South African NIHL Regulations, was restrictive and does not offer a broad high-frequency spectrum sufficient to identify early signs of ONIHL.[14,15] This offers an opportunity to review the STS definition and to redefine the audiometry surveillance protocol as a risk assessment tool specific for the South African mines to accurately track mineworkers' hearing deterioration and predict STS as a risk for ONIHL.

Age and sex are well documented risk factors associated with ONIHL,[3,24] thus, susceptibility to hearing loss cannot be separated from the two risk factors.[25] Our findings from our regression model indicated that age was a significant risk associated with hearing deterioration for the mineworkers who presented with STS at mild and moderate hearing sensitivity. Our findings agree with previous study findings,[3,26,27] but our findings went further to show the severity of hearing deterioration for these mineworkers. In addition, we have provided evidence-based findings of the risk assessment tools (personal noise measurements and audiometry records) used by the mine to track the mineworkers' hearing function.[18,19] Therefore, a concerted effort by the study mine has been acknowledged in our findings, and other mines in South

African mines may reflect on their outcomes for risk-based audiometry surveillance and the effectiveness of their HCPs using our study as a guide.

Duration of noise exposure (hours/weeks/year) in any environment, either at work or elsewhere, increases the risk for other health conditions such as heart conditions, discomfort and sleep among adults,[28,29] and, specific to our case, the risk for ONIHL. In South Africa, the legislated work shift is 8 hours per day and 40 hours per week.[30] Our study findings indicated that most (n = 445; 85.4%) mineworkers worked more than 8 hours per shift. However, our study findings indicated that shift duration was not significantly associated with changes in STS. But it must be noted that most of the sampled mineworkers were exposed to personal noise levels less than 85 dB(A), hence, duration of exposure of more than 8 hours was not a factor as indicated in our findings. Although our findings provided evidence that most of the mineworkers worked for more than 8 hours per shift, future studies could investigate the cumulative effect caused by extended shift duration for mineworkers exposed to noise levels greater than 85 dB(A), to account for the associated risk of ONIHL for the South African mineworkers. The South African mines could use datasets drawn from sampled personal noise measurements since they contain duration of noise exposure (shift/hour) for the mineworkers to guide future decision-making towards the prevention of ONIHL.

Conclusion

Mineworkers' age was significantly associated with their STS and was also a significant risk factor that had the predictive ability to show early signs of hearing deterioration associated with ONIHL for this group of mineworkers. Although the sampled mineworkers were mostly exposed to personal noise levels that were less than 85 dB(A) and mostly presented with STSs that were within normal hearing levels (≤25 dBHL), small shifts in hearing thresholds were significantly associated with age. Hence, age was significantly associated with the risk for ONIHL for this group of mineworkers. Since their personal noise exposure measurements were less than 85 dB(A), this confirms our finding of no association between noise and STS. Thus, any shift in hearing threshold, even when the STS were within normal hearing limits, was imperative and should be reported. This is the first time that personal noise measurements have been used to predict early signs of hearing deterioration and to determine the associated risk for ONIHL for the mineworkers employed by the South African mines. Duration of exposure to occupational noise for more than 8 hours a shift was not a significant risk factor associated with hearing deterioration, since most mineworkers were exposed to personal noise levels less than 85 dB(A). Hence, work shift of more than 8 hours in the absence of exposure to high personal noise levels was not a risk factor for hearing deterioration. However, implications for other health risks associated with long working hours may not be overlooked. The methods used by the mine to collect the mineworkers' records for audiometry surveillance risk assessment purposes could be considered as CoP for standard procedures to track and identify risks associated with and towards the prevention of ONIHL for the South African mineworkers. We highlighted the usefulness of personal noise measurements as risk-based assessment tools for audiometry surveillance that have measurable outcomes. However, careful interpretation of our findings should be undertaken as findings may be mine-specific, some outliers were managed during data analysis, particularly where area noise levels were higher than expected, measurements were capped to a maximum of 105 dB(A). The role of the occupational hygienist in noise exposure measurements cannot be overlooked.

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Author Contributions

L.N. conceptualised the idea for the research, as well as the design and methodology, with assistance from G.N. L.N. collected data for the study and analysed it in preparation for the manuscript write-up. G.N. reviewed and guided the final data analysis in preparation for the writing of the study findings. L.N. was the lead author who drafted the full manuscript, and G.N. provided the final review. Both authors read and approved the final manuscript.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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Ethical statement

Ethical approval

This study's ethical clearance was approved by the University of the Witwatersrand Human Research Ethics Committee (clearance certificate no. M180273).

Consent for publication

Permission to use the mineworkers' data was granted by the mine management.

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