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Review

Hearing loss in miners exposed to high noise levels: A systematic review and *meta*-analysis of the last 10 years

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ABSTRACT

Background: Mining workers are frequently exposed to noise levels exceeding recommended limits, leading to noise-induced hearing loss (NIHL), a major occupational disease worldwide. This study aimed to assess the relationship between miners' hearing loss and exposure to high noise levels.
Methods: A systematic review and *meta*-analysis following the PRISMA guidelines was conducted using PubMed, Scopus, and Web of Science for articles published between 2014 and 2024. The Joanna Briggs Institute (JBI) tools were used to evaluate the methodological quality of the studies. Heterogeneity was calculated using the I2 index and publication bias using Egger's test.
Results: A total of 15 studies were included in this systematic review. 40% were conducted in African countries, with South Africa being the country with most studies. 80% of the studies made no mention of the type of mine, while only 20% specified whether they were open-pit or underground mines. 67% of the studies considered the age of the workers as a risk factor for Hearing Loss (HL), while 33% made no mention of this variable. Regarding the sex of the participants, 67% of the studies evaluated samples that included both men and women, 20% did not specify the sex of the subjects, and 13% only included men. Notably, in 33% of the studies, male sex was associated with an increased risk of HL.
Conclusions: Findings highlight the need for extended rest periods, improved hearing monitoring, increased involvement of audiologists in noise control, and better training for miners on protective measures. These steps could help mitigate noise exposure and reduce HL among mining workers.

1. Introduction

Noise is defined as an unwanted sound, which is usually loud, unpleasant, and undesirable, and can be characterised according to its intensity and frequency (Nair, 2014). Excessive noise has negative effects on health, such as high blood pressure, hearing impairment, and adrenaline production, among others. Prolonged exposure to excessive noise levels can lead to a permanent degenerative process, which may result in Noise-Induced Hearing Loss (NIHL) (Nair, 2014). NIHL is a major health problem and one of the most common forms of Hearing Loss (HL), as it involves a permanent change in auditory thresholds caused by prolonged exposure to high noise levels (usually occurring at higher frequencies (3–6 kHz)), as a direct cause of damage to the sensory hair cells in the inner ear (Sliwinska-Kowalska & Davis, 2012) (Vaisbuch et al., 2018). Several studies have shown that factors such as age, sex, and type of occupation may be associated with HL and cardiovascular disease in workers (Zhao et al., 2021; Mai & Howell, 2023; Lie et al., 2016; Basner et al., 2014). Other studies have shown that workers undergoing treatment for tuberculosis (TB), human immunodeficiency virus (HIV), and/or cancer are at increased risk of developing NIHL

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(Khoza-Shangase, 2020).

NIHL is a common occupational disease and a major global health issue (Śliwińska-Kowalska & Zaborowski, 2017), and it is one of the most prevalent occupational diseases in many industrialised countries (Sayapathi et al., 2014). The World Health Organization (WHO) estimates that 16 % of cases of HL have been caused by exposure to occupational noise (WHO, 2019). In South Africa, NIHL is among the top three occupational diseases in the Mining industry (Department of Employment and Labour South Africa (DEL), 2020). In the United States (US), it is estimated that 56 % of workers in the US Mining sector are exposed to hazardous occupational noise each year (66 % with a history of occupational noise exposure). Also, 27 million workers are exposed to hazardous noise levels at or above 85 dBA in the US (Masterson, Morata & Themann, 2025).

Overall, sounds above 85 dB are considered harmful, depending on the duration and frequency of exposure and on whether hearing protection devices are used. Studies indicate that miners are exposed to higher than recommended noise levels due to the use of machinery, sanders, grinders, and power hammers, all of which increase the risk of HL (Ismail et al., 2013; Lewkowski et al., 2017). Additionally, Pyykko et al. (1989) found that workers suffering from Vibration White Finger (VWF) from the use of vibrating tools experienced greater HL than those exposed to the same conditions, but had no VWF. Overall, the inability to clearly perceive sounds due to HL can increase the risk of accidents and injuries both at work and at home, affecting the safety and well-being of workers and their environment (Chen et al., 2020).

Although the primary cause of NIHL is noise exposure, there are other effects of noise that should also be considered. These include, among others, reduced individual work performance, lower work-related quality of life (Abbasi et al., 2024), poor sleep quality, daily life health conditions, workplace health problems among workers (Jo & Baek, 2024), and mental disorders (Monazzam-Esmaielpour et al., 2021).

Noise management in the mining sector is not adequately monitored, mainly because it is not given the necessary attention as a significant health problem. Currently, information and literature on the disease process, as well as on preventive measures in industries with high risk of noise exposure, are lacking. Despite the implementation of hearing conservation programmes, workers continue to develop HL (Borchgrevink, 2003). In countries such as South Africa, where the prevalence of NIHL is high, inadequate responses to the burden of the disease can be attributed to an inability to prevent the disease. This has led to the view that health professionals are not effective in preventing HL (Edwards & Kritzinger, 2012; Moroe et al., 2018; Ntlhakana et al., 2015), despite having been operating in South African mines since 1988 (Franz & Phillips, 2001). Currently, few studies have focused on employee attitudes towards the disease and the use of hearing protection equipment. Existing studies show that, although workers generally acknowledge the negative consequences of NIHL, this does not always motivate a change in their behaviour (Hansia & Dickinson, 2010; Mizan et al., 2014; WHO, 2004). This fact emphasises the importance of understanding employees' beliefs and attitudes in order to design more effective prevention strategies. With such information, employers will be better able to address underlying issues and develop effective measures to control noise exposure and reduce the incidence of HL.

The aim of this study was to assess the relationship between the occurrence of HL in miners and exposure to high noise levels.

2. Methods

2.1. Study design

Following the guidelines of the PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) statement (Page et al., 2021), a systematic review was conducted on studies dealing with the relationship between the occurrence of HL and exposure to high noise levels in miners. This systematic review was based on a protocol registered in the International Prospective Register for Systematic Reviews (PROSPERO), with identification code CRD42025630967.

2.2. Search strategy

Searches were carried out in the Pubmed, Web of Science, and Scopus electronic databases. For this, the key words obtained from the research question were used following the PEO format (Munn et al., 2018) (Table 1).

From these key words, the following descriptors obtained from the Medical Subject Headings (MeSH) were used: Deafness, Miners, and Noise. Synonymous terms were used to expand the scope of the search based on the MeSH descriptors, which were linked using the Boolean operators And and Or. Table 2 shows the search strategy used for each of the above databases, conducted on 2 December 2024.

2.3. Selection criteria

The following criteria were used for the selection of articles:
Inclusion criteria:

- Articles published in the last 10 years.
- Type: original articles and *meta*-analyses.
- Articles whose source of data collection was the miners themselves.
- Articles with a sample consisting of miners or miners and other professions (with data disaggregated by occupation).
- Articles measuring any of the following variables and/or effects: daily decibel exposure above 85dBA, use of Personal Protective Equipment (PPE), level of knowledge, altered levels in audiometry, co-exposure and differences between type of mine, age, sex, and other related variables.

Exclusion criteria:

- Articles that after applying the quality assessment tool presented low scientific-technical quality.
- For the *meta*-analysis: studies which do not allow for the calculation of HL prevalence among miners.

2.4. Data collection and extraction

The entire search was conducted by a single researcher. To this end, duplicated studies were eliminated and, after reading abstracts and titles, articles that could be included according to the established criteria were selected.

The full texts of the studies were reviewed to decide upon their inclusion or exclusion in the systematic review.

2.5. Methodological quality assessment

The methodological quality of the selected studies was independently assessed using the critical appraisal tools for research from the Joanna Briggs Institute (JBI) at the University of Adelaide, Australia (Jordan et al., 2019). These tools allow measuring the methodological quality of the selected studies and assessing the extent to which the risk

Table 1
PEO format: key words.

PEO format: key words.	
Population	Miners
Exposure	Exposure to high noise levels
Outcome	Development of hearing loss or hypoacusis
Research question	*Is there a relationship between the occurrence of hearing loss in miners and exposure to high noise levels?*

Table 2
Search strategy.

Database	Search strategy	Results
Pubmed	(((((noise[MeSH Terms]) OR (explosions[MeSH Terms])) OR (Hydraulic Fracking[MeSH Terms])) OR (noise*[Title/Abstract] OR explosion*[Title/Abstract] OR Fracking[Title/Abstract] OR Hydrofracking[Title/Abstract] OR Fraccing[Title/Abstract] OR Hydrofracturing*[Title/Abstract] OR Hydraulic Fracturing[Title/Abstract])) AND ((Miners[MeSH Terms]) OR (Miner*[Title/Abstract] OR Mineworker*[Title/Abstract] OR Mine Worker*[Title/Abstract] OR Mining[Title/Abstract]))) AND (((deafness [MeSH Terms]) OR (Hearing loss[MeSH Terms])) OR (Deaf*[Title/Abstract] OR loss hear*[Title/Abstract] OR Hypoacus*[Title/Abstract]))	144
Scopus	noise* OR explosion* OR Fracking OR Hydrofracking OR Fraccing OR Hydrofracturing* OR "Hydraulic Fracturing" (Topic) AND Miner* OR Mineworker* OR "Mine Worker*" OR mining (Topic) AND Deaf* OR "loss hear*" OR Hypoacus* (Topic)	270
Web of Science	(noise* OR explosion* OR fracking OR hydrofracking OR fraccing OR hydrofracturing* OR "Hydraulic Fracturing") AND TITLE-ABS-KEY (miner* OR mineworker* OR "Mine Worker*" OR mining) AND TITLE-ABS-KEY (deaf* OR "loss hear*" OR hypoacus*))	101
Date of search: 2 December 2024	Total: 515	

of bias in the design, implementation, and/or analysis has been minimised or avoided. The versions corresponding to cross-sectional quantitative studies (8 items) and cohort studies (11 items) were used, setting the cut-off point at 6 for the former and 8 for the latter in order to be included in this review (Table 3 and Table 4).

2.6. Data analysis

A random-effects *meta*-analysis was performed using the *meta*-analysis package from Statsdirect software (version 4.0.4) to estimate the prevalence of HL among miners. To estimate the prevalence, the total sample size and the sample of miners with HL from each study were used. A random-effects *meta*-analysis was chosen to calculate the mean prevalence rates and 95 % CI, as the number of studies included was greater than 10. Heterogeneity was calculated using the I2 index and publication bias using Egger's test.

3. Results

A total of 515 studies were identified (PubMed: 144; Web of Science: 270; and Scopus: 101), of which 29 were duplicates. After screening, 15 studies were finally selected for inclusion in this systematic review (Fig. 1).

40 % of the studies were conducted in African countries (South Africa (n = 4); Tanzania (n = 1); and Ghana (n = 1)); 27 % in Asian countries (China (n = 3) and Iran (n = 1)); 13 % in both Australia (n = 2) and the Americas (Canada (n = 1) and the United States (n = 1)); and only 7 % in Europe (Norway (n = 1)).

In terms of study type, 67 % (n = 10) of the studies were descriptive cross-sectional studies and 33 % (n = 5) were descriptive longitudinal studies.

80 % (n = 12) of the studies did not mention the type of mine, with only 20 % (n = 3) specifying whether it was an underground or an open-pit mine. Regarding the type of extraction, 20 % (n = 3) of the studies were conducted in gold mines, 13 % (n = 2) in coal mines, 7 % in both platinum (n = 1) and aluminium mines (n = 1), and 53 % (n = 8) did not provide any data on this respect.

67 % (n = 10) of the studies identified age of workers as a risk factor for HL, while 33 % (n = 5) made no mention of this variable.

As for the sex of the participants, 67 % (n = 10) of the studies evaluated samples that included both males and females, 20 % (n = 3) did not specify the sex of the subjects, and 13 % (n = 2) only included males. In 33 % (n = 5) of the studies, male sex was associated with an increased risk of HL. Overall, the studies were mainly focused on manual workers, as they were directly exposed to the noise sources, in contrast to administrative staff.

All studies were assessed using the Joanna Briggs Institute (JBI)

Table 3
Scores of cross-sectional observational studies.

Study	JBI	Inclusion criteria are clearly defined	The participants and the environment are described in detail	Exposure was validly and reliably measured	The criterion used to measure the condition was objective	Confounding factors were identified	Strategy for dealing with confounding factors	Validly and reliably measured results	Appropriate statistical analysis was used
Gyamfi et al. (2016)	8/8	YES	YES	YES	YES	YES	YES	YES	YES
Musiba et al. (2015)	7/8	YES	YES	YES	YES	YES	NO	YES	YES
Naicker (2024)	7/8	YES	YES	NC	YES	YES	YES	YES	YES
Zare et al. (2019)	6/8	YES	YES	YES	YES	NO	NO	YES	YES
Liebenberg et al. (2023)	6/8	YES	YES	YES	YES	NO	NO	YES	YES
Lie et al. (2016)	7/8	YES	YES	YES	YES	YES	NO	YES	YES
Khoza-Shangase (2020)	7/8	YES	YES	YES	YES	YES	NC	YES	YES
Masterson et al. (2016)	7/8	YES	YES	YES	YES	YES	NC	YES	YES
Jin et al. (2024)	8/8	YES	YES	YES	YES	YES	YES	YES	YES
Zhou et al. (2020)	7/8	YES	YES	YES	YES	YES	NC	YES	YES

NC: Not clear

Table 4
Scores of longitudinal observational studies.

Study	JBI	Both groups were similar and from the same population.	Exposures were measured in a similar way to allocate subjects to exposed and unexposed groups	Exposure was validly and reliably measured	Confounding factors were identified	Strategy for dealing with confounding factors	Groups/participants were free of the outcome at the start of the study	Validly and reliably measured results	Follow-up time was reported	Follow-up was completed and, if not, reasons for loss to follow-up were described and analysed	Strategies to address incomplete follow-up	Appropriate statistical analysis was used
Grobler et al. (2020)	10/11	YES	YES	YES	YES	YES	YES	YES	YES	YES	NC	YES
Ntlhakana et al. (2020)	8/11	YES	YES	YES	YES	NO	YES	YES	YES	NO	NO	YES
Donoghue et al. (2016)	8/11	YES	YES	YES	YES	NO	YES	YES	YES	NO	NO	YES
Turcot et al. (2015)	8/11	YES	YES	YES	YES	YES	YES	YES	NO	NO	NO	YES
Sun et al. (2021)	9/11	YES	YES	YES	YES	YES	YES	YES	YES	NC	NO	YES

NC: Not clear

critical appraisal tools for research. Scores were medium–high for all cross-sectional and longitudinal observational studies.

Table 5 shows the classification of the 15 studies included in the systematic review (Gyamfi et al. (2016); Musiba (2015); Naicker (2024); Zare et al. (2019); Grobler et al. (2020); Ntlhakana et al. (2020); Donoghue et al. (2016); Liebenberg et al. (2023); Turcot et al. (2015); Sun et al. (2021); Lie et al. (2016); Khoza-Shangase (2020); Masterson (2016); Jin et al. (2024); Zhou et al. (2020)). They were classified according to the following criteria: author and year of publication; objective; design; sample; methods/instruments; main findings; and the score obtained after quality assessment of the studies.

A *meta*-analysis of the prevalence of HL among miners was performed based on studies that included the relevant information (n = 12). The samples affected by HL in each study, regardless of scale or instrument, were included in the *meta*-analysis. The total sample of miner groups in the *meta*-analysis was n = 29,581, with a prevalence value of 28 % (95 % CI: 15 %–42 %). Fig. 2 shows the corresponding forest plot. Random effects were used due to high I2. The I2 value was 99.5 %, and the Egger test value showed no publication bias.

4. Discussion

This study examined and reviewed the literature on HL and deafness in miners over the last 10 years. The aim of this study was to assess the relationship between the occurrence of HL in miners and exposure to high noise levels. All studies were consistent in this aspect, as those subjects who were exposed to high noise levels during their working day showed HL.

4.1. Noise exposure and its relationship with hearing loss

Exposure to high noise levels was found to increase the likelihood of HL and many studies reported such observations. Sun et al. (2021) confirmed that workers subjected to prolonged noise exposure can develop high frequency HL (Abujamra et al., 2013). This is the case in the mining sector, where high frequency HL is very common, which is justified by the fact that heavy equipment and machinery are required for the extraction of minerals, resulting in miners being exposed to high levels of noise (Abujamra et al., 2013) (Tripathy & Nanda, 2015). The use of machinery in work areas is a major source of noise. The study by Gyamfi et al. (2016) showed that the use of machinery produced noise levels ranging from 85.5 dBA to 102.7 dBA, which could damage the hearing health of workers, as the threshold limit of 85 dBA recommended by the World Health Organization (Berglund et al., 1999) was exceeded. In the study by Liebenberg et al. (2023), mobile equipment, vehicles, and the different tools used in the workplace were also considered the main sources of noise, as values ranging between 80 and 120 dBA were obtained after measuring the noise generated by these sources. In contrast, the study by Musiba (2015) contradicted these results, finding that miners who did not use mobile equipment had a higher prevalence of NIHL (70 %), justified by the fact that miners who used mobile equipment as part of their main tasks were more likely to be exposed to lower noise levels.

The duration of exposure was also a factor in the increase in HL. Many studies found that the older the subjects were and the longer they had been working in the mine, the greater the risk of suffering HL (Ntlhakana et al., 2020; Zhou et al., 2020; Liebenberg et al., 2023; Gyamfi et al., 2016; Sun et al., 2021). The study by Zhou et al. (2020) related HL to exposure to high noise levels and longer duration, and this is justified because outer hair cells damaged by high noise can spread the damage to inner hair cells, supporting cells, cochlear vessels, and spiral ganglion cells upon continued exposure (Zhu et al., 2015). In contrast, Grobler et al. (2020) suggested in their study that before hair cell damage occurs, the destruction of synaptic connections between hair cells and cochlear neurons takes place (Fernandez et al., 2015; Liberman, 2017).

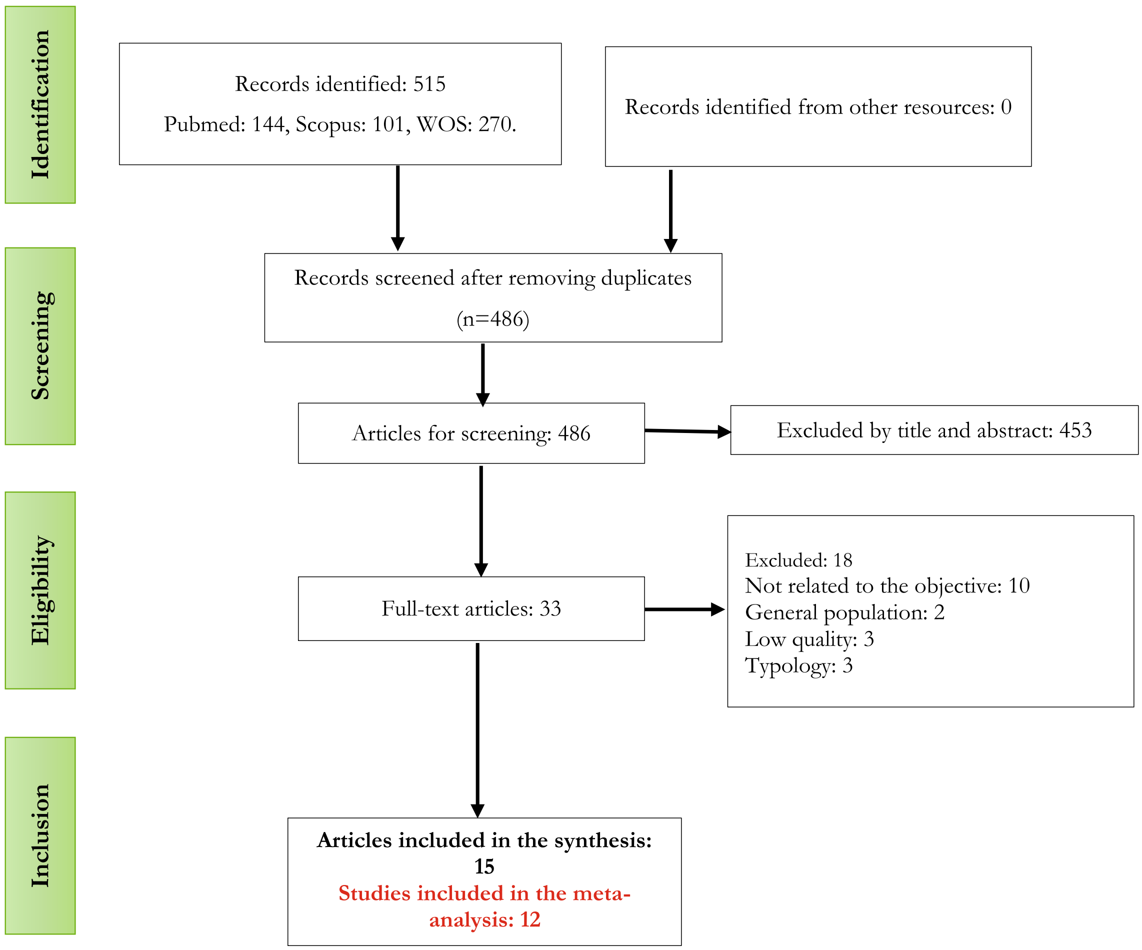

Fig. 1. Search results (Flowchart – PRISMA).

4.2. Relationship between the type of mine and type of extraction and hearing loss

80 % of the studies did not specify the type of mine where the samples had been taken, while 20 % did. This is important, as studies such as the one developed by Musiba (2015) showed a higher exposure to elevated noise in underground mines, with a higher percentage of miners with NIHL (71 %) compared to workers in open-pit mines (22 %) (Musiba, 2015). Notably, this study did not provide a justification for the results obtained. The study by Sun et al. (2021) mentioned that many studies agreed that HL is related to the type of industry and company (Ai et al., 2019). Masterson (2016) also confirmed that the mining sector has the highest prevalence of workers with hearing impairment.

As for the type of material mined, Naicker's study (2024) selected a coal mine because, according to different studies, it is the type of mining where the highest proportion of miners with hearing impairment exists and the most common in not complying with noise restrictions (Roberts et al., 2017; Sun & Azman, 2018; Sun et al., 2019). On the other hand, the study by Liebenberg et al. (2023) was also conducted in a coal mine, but did not state why this type of mine was selected.

4.3. Miners' knowledge on noise exposure and hearing loss

The studies by Liebenberg et al. (2023) and Naicker (2024) focused on mine workers' knowledge on noise exposure and HL. Many studies agree that workers in the mining industry are aware of the risk of working in this type of sector due to high exposure to high noise, but cases of HL are still present. This can be seen in the study by Liebenberg et al. (2023), where their findings showed that workers were aware of the cause and effect of noise exposure, but their behaviour and actions did not match this belief. This can be justified by the fact that NIHL takes time to appear and is not perceived as a priority with regard to risk management. In the case of Naicker's (2024) study, the results also revealed that a high number of workers were aware of the potentially dangerous implications of loud noise for their hearing health (Naicker, 2024).

4.4. Hearing protection devices (HPDs)

Concerning hearing protection devices, the study by Gyamfi et al. (2016) reported that workers who did not use earplugs had auditory thresholds above 25 dB, meaning that they needed sounds of at least 25 dB or more to be heard. This shows that the use of HPDs reduces the likelihood of developing hearing impairment, in line with the results reported by other researchers. Naicker's study (2024) revealed that workers were aware of the effects of NHIL and knew when and how to use HPDs. Liebenberg et al. (2023) reported in their results the main reasons why the miners did not use the HPDs correctly: difficulty in maintaining a conversation, not feeling exposed to loud noise at all times, discomfort when using the devices, not being able to hear the signals correctly, and not being able to ensure a good fit of the devices. These results coincide with those obtained by Musiba (2015), who found that, although the company provided HPDs, there was still a high prevalence of HL, and this was explained by the workers' poor

Table 5
Characteristics of the studies included in the systematic review.

Studies	Objective of the study	Type of study	Sample	Methods/Instruments	Main findings	Quality of the studies
Gyamfi et al. (2016) Ashanti (Ghana) April to June 2012	To assess the extent of noise exposure and its influence on hearing capabilities among quarry workers in Ashanti region.	Descriptive cross-sectional	400 quarry workers	Structured questionnaires, physical examination, and audiological assessments.	All the machines used at the various quarries produced noise that exceeded the minimum threshold with levels ranging from 85.5 dBA to 102.7 dBA. 176 (44 %) of study respondents had hearing threshold higher than 25 dBA. 18 % and 2 % of these were moderately (41–55 dBA) and severely (71–90 dBA) impaired, respectively. Age, duration of work, and use of earplugs independently predicted the development of hearing loss. Use of earplugs showed a protective effect on the development of hearing loss (OR = 0.45; 95 % CI = 0.25, 0.84).	8/8
Musiba (2015) Tanzania	To determine the prevalence of NIHL and associated factors among miners in a major gold mining company operating in Tanzania.	Descriptive cross-sectional	246 miners	Audiograms obtained during periodic medical examinations.	A total of 246 audiograms were studied. The prevalence of NIHL was 47 %, with 12 % with poor hearing and 35 % with mild hearing impairment. The proportion of NIHL increased with total years of exposure to noise. Underground miners were more affected (71 %) than open pit miners (28 %). These findings were statistically significant. The highest proportion of miners with NIHL (60 %) was among the youngest age group (20–29 years).	7/8
Naicker (2024) Mpumalanga (South Africa)	To ascertain the attitudes and beliefs about NIHL and HPD use among employees at a large-scale underground coal mine in Mpumalanga.	Descriptive cross-sectional	241 miners	Self-administered questionnaires	Out of 241 completed surveys, this study found that 84 % were aware of when to replace earmuffs; 95 % believed wearing HPDs could prevent hearing loss in noisy environments; 83 % felt their hearing was impacted by loud noise. Additionally, 86 % mentioned discomfort from earmuff pressure; 95 % emphasised HPD importance; and 95 % used HPDs around loud sounds. Moreover, 98 % knew how to properly wear earplugs, while lower education levels were linked to higher susceptibility to NIHL.	7/8
Zare et al. (2019) Iran 2018 period	To use the C5 algorithm to determine the weight of factors affecting the workers' hearing loss based on the audiometric data.	Descriptive cross-sectional	150 mining industry workers	Audiometries.	The results showed that in the first model (SPL < 70 dBA), the 8KHz frequency with weight of 31 % had the highest effect, the factors of work experience and the frequency of 250 Hz each with weight of 3 %, had the least effect, and the accuracy of the model was 100 %. In the second model (SPL 70–80 dBA) the frequency of 8KHz with weight of 21 % had the highest effect, the frequency of 250 Hz and the working experience each had the lowest effect with weight of 7 % and the accuracy of the model was calculated as 100 %. In the third model (SPL > 85 dBA), the 4KHz frequency with weight of 31 % had the highest effect, and the work experience with weight of 1 % had the lowest effect, and	6/8

(*continued on next page*)

Table 5 (*continued*)

Studies	Objective of the study	Type of study	Sample	Methods/Instruments	Main findings	Quality of the studies
					the accuracy of the model was 94 %. In the fourth model, the 4KHz frequency with weight of 22 % had the highest effect and 250 Hz and age each with weight of 8 % had the lowest effects; the accuracy of this model was calculated to be 99.05 %.	
Grobler et al. (2020) South Africa	To establish the relationship between hearing loss and age over time.	Descriptive longitudinal	2.583 miners	Audiological data	Base threshold values were higher for the NEG than for the NNEG across frequencies. All year-to-year increases in mean hearing thresholds were statistically significant (p 0.01). When correcting for age, increases in mean hearing thresholds were higher for the NEG than for the NNEG for HFA346 (3.5 dB vs. 2.9 dB decline over a 4-year period) but similar for LFA512 (0.6 dB vs. 0.7 dB decline). Uncorrected for age, increases in mean hearing thresholds were higher than when age was corrected for.	10/11
Ntlhakana et al. (2020) South Africa 2014 – 2017 period	To establish how miners with published risk factors associated with ONIHL were managed by the mine's hearing conservation practitioners as part of the HCP; to determine if the mine's hearing conservation practitioners could estimate miners' risk of ONIHL using baseline PLH as a hearing conservation measure; and to estimate the contribution of noise exposure to ONIHL risk.	Descriptive longitudinal	2.011 mine workers	Diagnostic audiometry records	The mean age of the miners (all male candidates) was 47 ± 8.5 years; more than 80 % had worked for longer than 10 years. Valid baseline audiometry records were available for only 34 % (n = 669) of the miners. Miners with a 0 % baseline PLH had a 20 % predicted risk of ONIHL, and a 45 % predicted risk if they had a 40 % baseline PLH – these employees were referred. The noise exposure risk rankings revealed that 64.9 % (n = 1250) of the miners were exposed to 91 dBA – 105 dBA noise exposure levels and that 59 (80.8 %) diagnosed with ONIHL were exposed to noise levels of up to 104 dBA.	8/11
Donoghue et al. (2016) Australia 2006 – 2013 period	To report experience in reducing the incidence of age-corrected confirmed 10 dB hearing shifts (averaged over 2, 3 and 4 kHz) in employees in the primary aluminium industry in Australia over the period 2006–13.	Descriptive longitudinal	796 mining employees, 2631 refinery employees and 1091 smelter employees.	Annual audiometric data	Across all operations, hearing shift rates declined from 5.5 % per year in 2006 to 1.3 % per year in 2013 (*P* < 0.001). The decline in shift rates was greater in mines and refineries, where baseline shift rates were higher, than in smelter workers. Modest reductions in noise exposure occurred during the study period.	8/11
Liebenberg et al. (2023) Australia	To determine workers' attitudes towards noise prevention and control, perceptions on hearing loss, and management of workplace noise; and to identify barriers within current strategies that prevent effective management of hearing health in Australian mines.	Descriptive cross-sectional	72 mine workers	Online survey questionnaires	Almost 60 % of respondents indicated that they had had high noise exposure for 10 years or more, and had some trouble hearing, mostly associated with infrequent tinnitus. Nearly 71 % of these workers believed that the noise control strategies in their workplaces were effective, but this mostly referred to the use of hearing protection devices.	6/8
Turcot et al. (2015) Quebec (Canada)	To determine whether hearing impairment is worse in noise-exposed workers with VWF than in workers with similar noise exposures but without VWF.	Descriptive longitudinal	59,339 workers (15,757 in the mining and forestry sector)	Audiometric and occupational disease data	15,751 vibration-exposed workers were identified in an overall source population of 59339. Workers with VWF (n = 96) had significantly worse hearing at every frequency	8/11

(continued on next page)

Table 5 (*continued*)

Studies	Objective of the study	Type of study	Sample	Methods/Instruments	Main findings	Quality of the studies
					studied (500, 1000, 2000 4000 Hz) compared with other mining and forestry workers without VWF.	
Sun et al. (2021) Sichuan (China) 2014 – 2017 period	To construct and validate a risk model for HFHL and to develop a nomogram for predicting the individual risk in noise-exposed workers.	Descriptive longitudinal	32,121 workers exposed to occupational noise	Data from the National Key Occupational Diseases Survey-Sichuan	A total of 10.06 % of noise-exposed workers had HFHL. Age (OR = 1.09, 95 % CI: 1.083–1.104), male sex (OR = 3.25, 95 % CI: 2.85–3.702), noise exposure duration (NED) (OR = 1.15, 95 % CI: 1.093–1.201), and a history of working in manufacturing (OR = 1.50, 95 % CI: 1.314–1.713), construction (OR = 2.29, 95 % CI: 1.531–3.421), mining (OR = 2.63, 95 % CI: 2.238–3.081), or for a private-owned enterprise (POE) (OR = 1.33, 95 % CI: 1.202–1.476) were associated with an increased risk of HFHL ($P < 0.05$).	9/11
Lie et al. (2016) Nord-Trøndelag (Norway)	To test 2 spreadsheet models to compare the observed with the expected hearing loss for a Norwegian reference population.	Descriptive cross-sectional	18,858 screened reference population and 38,333 unscreened population	Data from the Nord-Trøndelag Hearing Loss Study (NTHLS).	Hearing of office workers, train drivers, conductors and teachers differed little from the screened reference values based on the Norwegian and the NIOSH criterion. The construction workers, miners, farmers and military had an impaired hearing and railway maintenance workers and bus drivers had a mildly impaired hearing. The spreadsheet models give a valid assessment of the hearing loss.	7/8
Khoza-Shangase (2020) South Africa	To compare the hearing function of gold miners with (treatment group) and without (non-treatment group) a history of tuberculosis treatment in order to determine which group had increased risk of noise induced hearing loss. Furthermore, possible influence of age and HIV in these two groups was examined.	Descriptive cross-sectional	102 miners	Audiological records	Findings suggest that gold miners with a history of tuberculosis treatment have worse hearing thresholds in the high frequencies when compared to those without this history, with evidence of a noise induced hearing loss notch at 6000 Hz in both groups. Pearson's correlations showed values between 0 and 0.3 (0 and − 0.3), which are indicative of a weak positive (negative) correlation between HIV and hearing loss, as well as between hearing loss and age in this population.	7/8
Masterson (2016) United States 2003 – 2012 period	To compare the prevalence of hearing impairment in nine industrial sectors in the United States.	Descriptive cross-sectional	1,413,789 workers exposed to noise	Audiograms	The mining sector had the highest prevalence of workers with some hearing impairment, and with moderate or worse impairment, followed by the construction and manufacturing sectors.	7/8
Jin et al. (2024) Chongqing (China)	To understand the health of workers exposed to occupational noise and to explore the influencing factors related to workers' health, especially the impact of noise on workers' hearing.	Descriptive cross-sectional	1,125 workers exposed to occupational noise	Demographic information, occupational history, clinical physical examination information, and noise detection information of the working environment.	The prevalence rates of abnormal ECG, BP, and PTA were 21.9 % (246/1125), 27.8 % (313/1125), and 18.0 % (202/1125), respectively. Male workers accounted for 78.8 %. Compared with male workers, female workers had a lower prevalence of abnormal PTA (OR = 0.28, 95 % CI = 0.16–0.50). Workers working in medium enterprises had a lower prevalence of abnormal BP than workers in micro enterprises (OR = 0.36, 95 % CI = 0.19–0.66). The prevalence of abnormal BP and	8/8

(*continued on next page*)

Table 5 (*continued*)

Studies	Objective of the study	Type of study	Sample	Methods/Instruments	Main findings	Quality of the studies
					PTA of workers increased with age. After adjusting for age, sex, and body mass index, the prevalence of abnormal ECG of mining workers was higher than that of manufacturing workers (OR = 1.54, 95 % CI = 1.07–2.24), and the prevalence of abnormal PTA had a rising trend with the increase in noise exposure value.	
Zhou et al. (2020) China December 2019 to February 2020	To analyse the prevalence and characteristics of occupational NIHL in the Chinese population using data from relevant studies.	Descriptive cross-sectional	71,865 workers	Databases	A total of 71,865 workers aged 33.5 ± 8.7 years were occupationally exposed to 98.6 ± 7.2 dB(A) (A-weighted decibels) noise for a duration of 9.9 ± 8.4 years in the transportation, mining and typical manufacturing industries. The prevalence of occupational NIHL in China was 21.3 %, of which 30.2 % was related to high-frequency NIHL (HFNIHL), 9.0 % to speech-frequency NIHL, and 5.8 % to noise-induced deafness. Among manufacturing workers, complex noise contributed to greater HFNIHL than Gaussian noise (overall weighted OR (OR) = 1.95). Coexposure to noise and chemicals such as organic solvents, welding fumes, carbon monoxide, and hydrogen sulfide led to greater HFNIHL than noise exposure alone (overall weighted OR = 2.36). Male workers were more likely to experience HFNIHL than female workers (overall weighted OR = 2.26). Age, noise level, and exposure duration were also risk factors for HFNIHL (overall weighted OR = 1.35, 5.63 and 1.75, respectively).	7/8

HPD: Hearing Protection Devices; **ECG**: Electrocardiogram; **HCP**: Hearing Conservation Programmes; **HFA346**: High-frequency average (average of audiological thresholds for 3 kHz, 4 kHz and 6 kHz); **HFHL**: High-Frequency Hearing Loss; **HFNIHL**: High frequency noise-induced hearing loss; **CI:** Confidence Interval; **LFA512**: Low-frequency average (average of audiological thresholds for 0.5 kHz, 1 kHz and 2 kHz); **NED**: Noise exposure duration; **NEG**: Noise exposed group; **NIHL**: Noise-Induced Hearing Loss; **NIOSH**: National Institute for Occupational Safety and Health; **NNEG**: Non-noise exposed group; **ONIHL**: Occupational noise-induced hearing loss; **OR**: Odds ratio; **BP**: Blood Pressure; **PLH**: Percentage loss of hearing; **POE**: Private-owned enterprise; **PTA**: Pure Tone Audiometry; **SPL**: Sound pressure level; **HIV**: Human immunodeficiency virus; **VWF**: Vibration White Finger.

compliance with protective measures. Thus, this would indicate that workers are not well informed about the use of HPDs and the consequences of not wearing them (Liebenberg et al., 2023). Furthermore, Liebenberg et al. (2023) considered HPDs to be the last line of defence against HL as workers would be unprotected against loud noise if the devices failed or malfunctioned.

Grobler et al. (2020) referred to different studies showing how hearing protection programmes established in different mines to reduce HL in workers still produced poor results. This can be justified because audiologists are hardly involved in the creation and implementation of such programmes (Moroe & Khoza-Shangase, 2018). Jin et al. (2024) also stressed the importance of hearing protection programmes, arguing that workers exposed to noise for long periods of time may exhibit reduced attention span and reduced awareness, which can lead to safety accidents in the workplace.

4.5. *Age as a risk factor for hearing loss*

Many studies have reported a relationship between the age of workers and HL. The study by Jin et al. (2024) found that increasing age led to more rapid hearing impairment and more severe HL, especially in men. Similar results were obtained by Grobler et al. (2020), Gyamfi et al. (2016), Masterson (2016), Ntlhakana et al. (2020), Zare et al. (2019), and Zhou et al. (2020).

On the contrary, the study by Musiba (2015) revealed that the highest proportion of miners with HL was found among the younger age group (20–29 years), explained by the fact that the mining methods used to teach the new miners were less mechanised. This result does not agree with the existing literature, where increasing age has always been associated with an increased likelihood of HL.

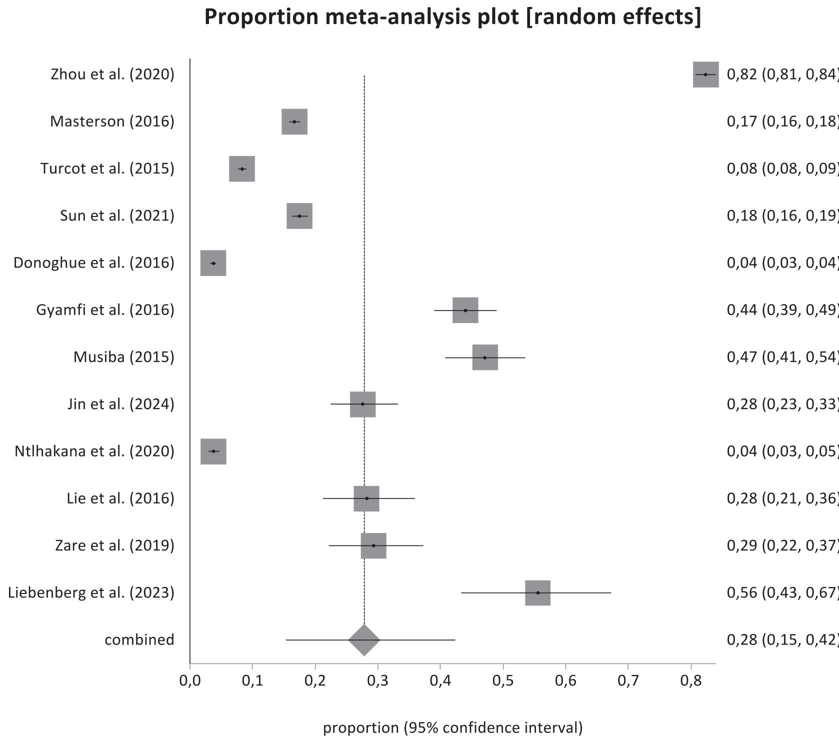

Fig. 2. Meta-analysis of proportions plot (random effects).

4.6. Sex as a risk factor for hearing loss

When considering the sex of workers as a risk factor for HL, the study by Sun et al. (2021) showed that men generally suffer more effects after occupational noise exposure. This finding is explained by the fact that women may suffer less HL due to oestrogen and its signalling pathways, which has been demonstrated in several studies (Nelson et al., 2005; Shuste et al., 2019). In addition, poor lifestyles, lower importance given to hearing health, and higher exposure to loud noise related to the jobs carried out also account for increased HL in men (Jin et al., 2024; Sun et al., 2021). Zhou et al. (2020), Ntlhakana et al. (2020), Masterson (2016), and Jin et al. (2024) also presented similar results, attributing increased HL to the male sex. In contrast, the study by Musiba (2015) found that more men were affected by HL due to a population bias, as there tend to be more male workers in the mining industry. The only study that showed a higher prevalence among women than men was the one by Liebenberg et al. (2023), where subjects volunteered to participate in the study.

4.7. Influence of tuberculosis on hearing loss

The study by Khoza-Shangase (2020) showed that miners with a history of tuberculosis treatment had a higher risk of developing HL than those without such treatment. This is because the drugs used to treat tuberculosis cause HL in those with certain risk factors related to drug dosage, duration of treatment, nutrition, age of the patient, hearing status, etc. (Roland & Rutka, 2004). According to Roland & Rutka (2024), tuberculosis drugs affect the basal turn of the cochlea, causing HL (at high, medium, and low frequencies) and/or tinnitus. These results are consistent with those obtained in the study by Khoza-Shangase (2020). Meanwhile, the study by Ntlhakana et al. (2020) did not include information on TB/HIV treatment in the miners' data, but did highlight the importance of considering the relationship between TB/HIV treatment and increased HL, citing other studies that do address this issue (Ntlhakana et al., 2020).

4.8. Hearing loss due to combined exposure to noise and vibration

The study by Turcot et al. (2015) reported greater HL in workers with vibration white finger (VWF) at both high (>2000 Hz) and low (500 and 1000 Hz) frequencies, confirming the relationship between combined exposure to noise and vibration and NIHL. Pyykko et al. (1989) and Iki et al. (1990) also obtained similar results. Authors such as Zhu et al. (1997) found unclear evidence as to whether these results are obtained as a consequence of vibration exposure leading to an increased risk of HL or whether VWF is an indicator of increased susceptibility to NIHL. Several different theories have been proposed to explain why workers with VWF are at increased risk of NIHL: (1) sympathetic vasoconstriction affects cochlear blood flow causing ischaemic damage to hair cells (Hawkins, 1971); (2) vibration from tools is transmitted via bone conduction to the inner ear (Sutinen et al., 2007); (3) the pathophysiology behind vibration-induced HL could lead to increased porosity of blood vessels in the stria vascularis, as well as degenerative changes in the intermediate cells of the stria vascularis (Seki et al., 2001); and (4) influence of other factors such as vibration of the whole body (Manninen, 1984).

4.9. Co-exposure

The increase in HL due to co-exposure to specific chemicals and noise has become a new concern for researchers (Lewkowski et al., 2019). However, not many studies have addressed this issue, so further consideration of the effects of these toxic substances on HL would be of interest in the future (Yang et al., 2016). The study by Zhou et al. (2020), included in this systematic review, showed that co-exposure to noise and specific chemicals favoured HL. The reason for this is the auditory neurotoxicity induced by these chemicals. Ntlhakana et al. (2020) and Sun et al. (2021) were also in line with these results. These data can be linked to what Masterson, Morata, and Themann (2025) found about chemical and noise exposure at work in industries and other jobs in the United States, where 11 % had hearing loss and 7 % were exposed to noise and chemicals.

4.10. Limitations

This study has a number of limitations. Firstly, the studies included did not use the same measurement instruments, so the results may not be homogeneous. Secondly, the context in which the studies were conducted also differed. The type of mine, the protection devices, the laws of each country regarding admissible noise levels, etc. vary across studies, which also influenced the results and meant that certain studies may not be replicable in different types of mines. Thirdly, since the included articles were cross-sectional and longitudinal observational studies, the analysis of the conditions of a population at a specific time and place did not allow for definitive inferences of causality. Finally, it was not possible to determine whether the HL was occupational or non-occupational in origin due to the lack of complete occupational and medical histories with documented exposures.

5. Conclusion

The results of this study have shown that those miners who were exposed to high noise levels presented HL. In addition, variables such as type of mine, age, sex of subjects, use of hearing protection devices, combined exposure to noise and vibration, etc. may be influential factors. Differences in measurement methods and the context of the studies hinder the comparison and generalisation of results.

These results may have implications in terms of establishing more rest periods, considering further monitoring of miners' hearing functions, ensuring greater involvement of audiologists in noise management controls, investing in training miners on protective measures in the workplace to reduce noise levels and thus reduce the occurrence of HL. Besides, HL does not only affect the health of miners, but also the safety of the working environment and the daily life of the people who live with them.

6. Ethical responsibilities

All authors have confirmed the maintenance of confidentiality and respect for patients' rights in the author's responsibilities document, publication agreement and assignment of rights to Primary Care.

CRediT authorship contribution statement

María Victoria Parra-Cortés: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Juan Jesús García-Iglesias:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Juan Gómez-Salgado:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Blanca Prieto-Callejero:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Israel Macías-Toronjo:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Javier Fagundo-Rivera:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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