The interplay of occupational noise-induced hearing loss and middle ear disorders: towards comprehensive hearing conservation in Africa

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ABSTRACT

Background: Occupational noise-induced hearing loss (ONIHL) is preventable, particularly in low- and middle-income countries (LMICs). Middle ear disorders frequently co-occur with ONIHL, but remain neglected in hearing conservation programmes (HCPs). These conditions can complicate diagnosis, impair workers' ability to use hearing protection devices (HPDs), and exacerbate functional hearing deficits.

Objectives: The objectives of this review were to: 1) describe the prevalence and impact of middle ear disorders among noise-exposed workers, 2) examine the interplay between ONIHL and middle ear pathology in occupational settings, 3) explore the influence of systemic health factors, such as human immunodeficiency virus (HIV), on conductive hearing loss, and 4) identify gaps in current HCPs in African LMICs.

Methods: This narrative review included peer-reviewed articles, policy documents, and occupational health reports published from 2000 to 2024. PubMed, Scopus, Web of Science, Google Scholar, and African Journals Online (AJOL) databases were searched for relevant literature. Articles were included if they discussed HCPs, workplace safety regulations, and audiological health in Africa, or provided comparative insights from LMICs outside Africa. Thematic analysis was conducted to identify patterns, gaps, and policy implications.

Results: Eighteen of the 1 417 articles identified were included in the final synthesis. Most studies originated from LMICs, particularly in southern Africa, while several provided global comparative insights. The studies predominantly focused on workers in mining, manufacturing, and construction sectors. Thematic analysis revealed four core themes: 1) underdiagnosis of middle ear pathologies in occupational settings, 2) lack of enforcement of noise exposure regulations, 3) low compliance with HPDs, and 4) inadequate integration of audiological assessments in HCPs. Limited research addressing the dual burden of sensorineural and conductive hearing loss was noted, complicating intervention design in African LMICs.

Conclusion: The review demonstrated a clear disconnect between HCP implementation and the dual burden of sensorineural and conductive hearing loss. Addressing this gap requires an integrated approach that incorporates middle ear assessments, context-sensitive policy reforms, and feasible interventions such as mobile screening and task-shifting. Strengthening both the clinical and policy frameworks for occupational hearing health is essential for effective, inclusive, and sustainable prevention strategies in resource-constrained environments.

INTRODUCTION

Occupational noise-induced hearing loss (ONIHL) remains a public health concern, particularly in low- and middle-income countries (LMICs), where regulatory frameworks and workplace protections are often deficient.[1] Chronic exposure to hazardous noise levels leads to irreversible sensorineural hearing loss, due to damage to the hair cells in the cochlea.[2] Hearing loss impacts communication, social interaction, workplace productivity, and overall quality of life. Industries where ONIHL is most common include mining, construction, and manufacturing.[2]

Middle ear disorders such as chronic otitis media, tympanic membrane perforations, and eustachian tube dysfunction are often overlooked in occupational hearing conservation efforts, despite their potential to exacerbate hearing impairment and complicate diagnostic and management strategies.[3,4] While global reviews, such as that by Chen et al. (2020),[2] have shown declines in ONIHL in high-income countries (HICs) due to strict regulations and effective hearing conservation programmes (HCPs), these trends are not mirrored in LMICs.[1,5]

Middle ear conditions can result in conductive hearing loss (CHL), which compounds the effects of noise-induced sensorineural damage, making it difficult to identify the primary aetiology of hearing impairment.[5] In South Africa, the burden of human immunodeficiency virus (HIV) is high, and HIV-infected workers are at high risk of CHL due to opportunistic infections such as chronic otitis media, which are aggravated by occupational noise exposure.[5] However, most HCPs do not incorporate routine screening for HIV-related middle ear disorders, resulting in underdiagnosis and untreated hearing loss.

The economic burden of occupational hearing loss and middle ear disorders is often overlooked, despite evidence that hearing impairments significantly impact productivity, workplace safety, and quality of life.[6] Workers with hearing loss are at higher risk of workplace accidents and job instability.[7,8] Additionally, middle ear pathologies can affect workers' ability to use hearing protection effectively, as earplugs and other devices may worsen symptoms or become uncomfortable due to underlying ear conditions.[9,10] Studies have shown that workers exposed to noise exhibit altered middle

ear function, with changes in resonance and sound absorbance.[11] Thus, the co-occurrence of ONIHL and middle ear disorders poses unique challenges in hearing conservation.

In Africa, workers in mining, manufacturing, construction, and agriculture are frequently exposed to excessive noise without adequate protective measures.[12] These sectors contribute significantly to economic development, but they also expose workers to noise levels that exceed recommended safety thresholds set by the World Health Organization (WHO), the International Labour Organization (ILO), and others. A systematic review of middle ear pathologies among miners in South Africa found a high prevalence of chronic otitis media and tympanic membrane perforations, suggesting that these conditions may exacerbate the effects of ONIHL.[3] The high prevalence of middle ear conditions in African populations is due to factors such as recurrent untreated infections, poor healthcare access, and environmental conditions.[13] Research has also indicated that inadequate screening for middle ear pathologies in noise-exposed workers may lead to misdiagnosis, resulting in incorrect or delayed interventions.[14] These middle ear pathologies can interact with ONIHL in ways that complicate audiological assessment, amplify functional hearing deficits, and hinder rehabilitation efforts. Furthermore, hearing protection devices may be less effective or uncomfortable for workers with middle ear disorders, making compliance with safety measures challenging.[15] Another affected group is informal sector workers, who often have limited access to medical interventions and lack employer-sponsored hearing conservation measures. Without adequate screening and customised interventions, they are at risk of both progressive hearing loss and occupational exclusion.[4,16] Lack of comprehensive occupational HCPs that consider both ONIHL and middle ear disorders results in suboptimal prevention, diagnosis, and intervention strategies.

Research and policy initiatives in LMICs tend to focus on ONIHL in occupational settings, often ignoring middle ear conditions. In Africa, HCPs have been criticised for their narrow focus on noise exposure, without sufficient attention to other factors that contribute to hearing loss, including middle ear pathologies and chemical exposures.[4] This limits the effectiveness of HCPs, as workers with pre-existing or concurrent middle ear disorders may experience aggravated hearing loss due to workplace noise exposure. A longitudinal study, published in 2017, demonstrated that timely intervention and effective management of HCPs can reduce the incidence of noise-induced hearing loss, emphasising the importance of early screening for all auditory disorders, including middle ear conditions.[17] Additionally, many South African occupational health regulations fail to address the unique audiological needs of workers who present with both ONIHL and middle ear pathologies, leading to gaps in prevention, screening, and rehabilitation services.[5]

In this narrative review, we critically examined the intersection of ONIHL and middle ear disorders within occupational settings, with Africa as a focus, highlighting the implications for workplace HCPs,[1] and giving specific attention to the documented challenges of HCP implementation in South African mines.[19] The objectives of this review were to: 1) describe the prevalence and impact of middle ear disorders among noise-exposed workers, 2) examine the interplay between ONIHL and middle ear pathology in occupational settings, 3) explore the influence of systemic health factors, such as HIV, on conductive hearing loss, and 4) identify gaps in current HCPs in African LMICs.

METHODS

A narrative review[20] was chosen to synthesise diverse sources of literature, identify knowledge gaps, and provide a broad, contextualised understanding of how middle ear pathologies impact hearing conservation efforts in noise-exposed workers.

Literature search strategy

A systematic and transparent literature search was conducted, following the guidelines of Levac et al. (2010)[21] to ensure rigour, feasibility, and reproducibility. The search was performed across multiple electronic databases, including PubMed, Scopus, Web of Science, ScienceDirect, Google Scholar, CINAHL, EBSCOHost, MEDLINE, ProQuest, and African Journals Online (AJOL), as well as institutional repositories and relevant grey literature from the WHO, the ILO, and the African Union (AU).

The search strategy incorporated Medical Subject Headings (MeSH) and free-text terms, with Boolean operators. Key search terms were:
- 'occupational noise-induced hearing loss' OR 'ONIHL'
- 'middle ear disorders' AND 'occupational hearing loss'
- 'hearing conservation programmes' AND 'occupational health'
- 'occupational noise exposure in Africa'
- 'hearing conservation policies in LMICs'
- 'workplace hearing loss and middle ear pathologies'

Additional literature was identified through forward and backward citation tracking (i.e. examining studies that either cited or were cited by key sources) and manual searches of reference lists in key publications.

To ensure relevance and methodological rigour, the following inclusion and exclusion criteria were applied.

Inclusion criteria

- Studies published from 2000 to 2024 in English
- Empirical studies, systematic reviews, meta-analyses, and policy reports focusing on ONIHL and/or middle ear disorders in occupational settings
- Articles discussing HCPs, workplace safety regulations, and audiological health in Africa
- Studies from LMICs outside Africa that provided comparative insights

Exclusion criteria

- Studies not addressing occupational hearing loss or workplace noise exposure

Data extraction and analysis

A narrative synthesis methodology was applied systematically to extract, organise, and interpret findings from the selected literature. This approach followed established principles for conducting narrative reviews.[20] The initial search yielded 1 417 records, of which 32 full-text articles were evaluated for eligibility. Following detailed appraisal, 18 studies were included in the final synthesis (see Table 1). Two reviewers independently assessed study relevance and methodological appropriateness to enhance rigour and reduce selection bias.

Tables were developed to capture:
- Study characteristics (author, year, country, and study design – where specified)
- Industry sector and worker population studied

- Prevalence and impact of ONIHL and middle ear disorders
- Identified gaps in HCPs
- Policy and regulatory frameworks discussed
- Recommendations for occupational hearing health

A thematic analysis approach[22] was used to synthesise findings, categorise emerging themes, and identify patterns, challenges, and policy gaps related to ONIHL and middle ear disorders in African occupational health settings. The review included a critical appraisal of each study's design quality, relevance to African LMICs, and the applicability of findings to real-world occupational settings. Specifically, studies were examined for methodological robustness (e.g. clear sampling methods, reliable outcome measures), relevance to key industry sectors (such as mining or construction), and the inclusion of vulnerable worker populations. These criteria were not only used to determine study inclusion but also to guide thematic interpretation. For example, studies with stronger design rigour and direct focus on occupational noise and middle ear disorders in African settings were weighted more heavily in identifying key themes.

Thematic analysis, following a structured framework based on Braun and Clarke's[22] 2006 six- phase approach to thematic analysis, was conducted to synthesise and interpret findings across the included studies. An iterative approach allowed themes to emerge both inductively from the literature and deductively in alignment with the study objectives. Key themes were derived through close reading, comparative coding, and clustering of findings according to recurrent patterns related to ONIHL, middle ear pathology, and hearing conservation challenges. Particular attention was given to how these themes varied across geographical regions, industry sectors, and study designs. The themes highlighted both common and divergent experiences across African LMICs, with reference to global literature for comparative insight.

Thematic saturation was reached when the review of additional studies no longer yielded novel insights into the core themes, challenges, or policy gaps related to ONIHL and middle ear disorders, thereby confirming analytical completeness.[23]

Quality assurance and interpretation

While narrative reviews offer flexibility, rigorous methodological safeguards were implemented to ensure reliability and transparency,[24] viz. 1) systematic documentation of the search strategy and study selection process; 2) continuous refinement of the research focus as new insights emerged; 3) critical evaluation of selected studies for methodological soundness, relevance, and applicability; and 4) reflexivity to account for potential researcher biases and contextual influences on interpretation. These measures strengthened the credibility, validity, and reproducibility of the review's findings, while ensuring a balanced synthesis of perspectives on ONIHL and middle ear disorders in occupational hearing conservation.

Although formal ethical approval was not required, ethical integrity was maintained through comprehensive citation of all sources to uphold academic integrity and avoid plagiarism; use of publicly available, peer-reviewed research to ensure credibility; objective selection and analysis of studies to minimise bias; and acknowledgement of potential conflicts of interest. Additionally, efforts were made to incorporate diverse perspectives, recognise limitations in available data, and ensure transparency in reporting and interpretation of findings.[25]

RESULTS

Descriptive profile of the studies

The findings of this review are presented thematically to highlight the dual burden of ONIHL and middle ear disorders in African LMICs, and to illustrate how these conditions are addressed (or overlooked) within existing hearing conservation frameworks. Eighteen of the 1 417 studies initially identified were included in the final synthesis, of which 10 were deemed highly relevant as they directly addressed the intersection of ONIHL, middle ear pathology, and occupational hearing conservation within African contexts (Table 2). Eight were classified as moderately relevant; while not central to the study aim, they provided comparative or conceptual insights into occupational hearing health challenges in LMICs (Table 3).

The studies represented a diverse range of study designs and analytical approaches. Six were systematic or narrative literature reviews, which provided broad overviews of ONIHL prevalence, biological mechanisms, risk factors, and existing hearing conservation strategies.[2,3,8,15,18] These contributed background and highlighted global and regional trends. Four were cross-sectional studies that estimated the prevalence and characteristics of ONIHL and/or middle ear disorders among workers in specific industries.[11,26-28] Three were longitudinal cohort studies that provided insights into the progression of ONIHL over time and the long-term effects of workplace noise exposure.[17,29,30] Three occupational health policy reports and regulatory analyses examined the state of national and industry-level frameworks for hearing conservation, including enforcement gaps and structural weaknesses.[4,14,16] Two experimental or risk assessment studies assessed the auditory effects of noise exposure below regulatory limits and examined early markers of auditory dysfunction.[31,32]

Table 1. Summary of process used to select articles for final review

Step	Description	n
Identified through database searching	Peer-reviewed journal databases and indexed searches (PubMed, Scopus, Web of Science, AJOL, etc.)	1 417
Screened for relevance	Based on title and abstract review	1 417
Full-text assessed for eligibility	Comprehensive reading	32
Excluded after full-text review	Deemed not relevant	14
Identified via supplementary searches	Added to ensure completeness	0
Included in final synthesis	Highly or moderately relevant	18
Highly relevant	Directly addressed ONIHL, middle ear disorders, and African HCPs	10
Moderately relevant	Provided contextual or comparative insights	8

AJOL: African Journals Online, HCP: hearing conservation programme

Table 2. Comprehensive evidence synthesis of interplay of ONIHL and middle ear disorders in HCPs in the African context (highly relevant sources)

Study	Industry sector, worker population	Prevalence and impact of ONIHL and middle ear disorders	Gaps in HCPs	Policy and regulatory frameworks	Recommendations
Sebothoma (2020)[3] South Africa, cross-sectional study	Mining industry; mineworkers (South Africa)	Limited studies on middle ear pathologies in miners; suggests high prevalence due to trauma and infections; evidence suggests the presence of conditions like chronic otitis media	ONIHL research dominates; middle ear disorders are neglected; little integration of middle ear disorder assessments	MHSC regulations – South Africa	More research on middle ear pathologies, incorporation into HCPs
Chen et al. (2020)[2] global, literature review	Various industries, including mining, manufacturing, construction	ONIHL is one of the most prevalent occupational diseases; risk varies with genetics, environment, and exposure	Noise control measures exist, but implementation is inconsistent; lack of worker compliance	Global occupational health guidelines (NIOSH, WHO)	Stronger enforcement of noise regulations, better worker education, use of antioxidants for prevention
Hong et al. (2013)[15] global, review article	General occupational noise exposure	Individual susceptibility to NIHL varies, influenced by genetic and environmental factors	Poor implementation of noise exposure control; lack of personalised prevention strategies	NIOSH standards for noise exposure	Need for individualised risk assessments, better integration of middle ear screening in hearing conservation
Frederiksen et al. (2017)[17] Denmark, longitudinal cohort study	High-noise industries, including manufacturing (Denmark)	10-year study showed declining noise levels, but persistent hearing loss risk in early-exposed workers	Older workers with prolonged exposure face higher risk; late intervention limits effectiveness	Danish hearing conservation regulations; HPD policies in place, but compliance varies	Stricter regulations for older workers; longitudinal monitoring and early intervention needed
Habig and De Koker (2004)[14] South Africa, cross-sectional study	South African mines; gold mineworkers	High prevalence of middle ear disorders; 27.1% had middle ear pathologies detected via tympanometry; 49.7% via otoscopy	Mineworkers unaware of risks; occupational health personnel lack training in middle ear pathology; lack of screening for middle ear disorders in medical surveillance programmes	MHSC, South Africa	Tympanometry should be included in routine screening
Khoza-Shangase et al. (2020)[4] South Africa, mixed-methods study	African mining sector	73.2% of miners exposed to excessive noise (> 85 dB); ONIHL rates remain high despite HCPs	HCPs not effectively implemented, despite policies	MHSC, South Africa	Comprehensive, multi-component HCP implementation required; locally relevant policies needed
Le et al. (2017)[18] global, review article	Various industries with noise (global)	12% of the world population at risk for ONIHL; noise also impacts vestibular function and causes tinnitus	Hearing loss under-reported due to inadequate testing methods; lack of focus on vestibular impacts of ONIHL	WHO occupational noise guidelines	Need for improved diagnostic tools for early detection; exploration of pharmaceutical interventions like antioxidants and steroids
Yilmaz et al. (2022)[11] Turkey, cross-sectional study	Metal industry; industrial workers (Turkey)	Chronic noise exposure affects middle ear resonance and absorbance	Standard audiometry misses middle ear damage; tympanometry not widely used; no routine screening for subtle middle ear dysfunctions	No specific mention of policies	Wideband tympanometry should be included in occupational screening for early detection of middle ear changes
Setyawan (2021)[8] Indonesia, survey-based study	Various industries (Indonesia)	NIHL prevalent in industrial settings; linked to concentration loss, fatigue, and economic burden; leading to job loss and social effects	Hearing conservation is inconsistent; lack of worker education on risks	Indonesian occupational noise regulations	Education and awareness campaigns needed for workers; comprehensive HCP strategies
Park et al. (2016)[29] South Korea, analytical cross-sectional study	Shipyard workers (South Korea)	CHL may reduce ONIHL risk; mixed results on protective effect	Lack of research on CHL's role in ONIHL prevention	Korean Occupational Safety and Health Agency (KOSHA)	More research needed on interactions between CHL and ONIHL – CHL as a potential protective factor

CHL: conductive hearing loss, HCP: hearing conservation programme, HPD: hearing protection device, MHSC: Mine Health and Safety Council, NIOSH: National Institute for Occupational Safety and Health, NIHL: noise-induced hearing loss, ONIHL: occupational noise-induced hearing loss, WHO: World Health Organization

These studies[31,32] expanded the scope of the review by interrogating the adequacy of existing occupational noise exposure thresholds.

Eleven of the studies were conducted in the USA, UK, Sweden, Canada, Denmark, South Korea, and Turkey, where occupational noise regulations are strictly enforced.[28,30,31] Seven were conducted in LMICs – South Africa and Indonesia – highlighting unique challenges in policy enforcement, access to healthcare, and worker compliance with hearing protection measures.[3,8,14,27] Some studies provided comparative analyses of ONIHL prevalence and policy effectiveness worldwide, including in African LMICs.[7,16,18]

The studies focused on a range of industries with high occupational noise exposure risks, viz. mining (six studies), particularly in South Africa where mineworkers have high rates of both ONIHL and middle ear disorders, due to chronic exposure to underground noise and poor access to healthcare;[3,14] construction and manufacturing (five studies), due to high noise exposure, poor compliance with hearing protection devices (HPDs), and gaps in HCP implementation;[11,17,26] the general workforce (three studies assessed hearing health risks across education, agriculture, and urban workplaces);[7,16,28] shipyard and metal industry workers (two studies) that assessed how CHL and vibration affect ONIHL susceptibility;[29,32] and one study that explored hearing loss outside traditional industrial noise exposure settings (musicians and teachers).[31] Although mineworkers in South Africa may have better access to occupational healthcare than the general population, gaps in comprehensive audiological and otological services, especially for middle ear pathologies, remain a challenge.

Theme 1: Prevalence and occupational impact of ONIHL and middle ear disorders

Occupational noise-induced hearing loss remains the most prevalent occupational disease across multiple industries, primarily mining, construction, and manufacturing, with a high economic burden.[2,3,4] Studies highlight that middle ear pathologies, such as chronic otitis media, tympanic membrane perforations, and eustachian tube dysfunction, are common in occupational settings, particularly among mineworkers.[3,14] Noise exposure can affect

Table 3. Comprehensive evidence synthesis of interplay of ONIHL and middle ear disorders in HCPs in the African context (moderately relevant sources)

Study	Industry sector, worker population	Prevalence and impact of ONIHL and middle ear disorders	Gaps in HCPs	Policy and regulatory frameworks	Recommendations
Weier (2020)[32] USA, systematic review	Various industries using vibrating tools (construction, manufacturing)	Occupational exposure to hand-arm vibration may be associated with hearing loss, independent of noise exposure	Limited research on vibration-induced hearing loss; lack of standardised measurement protocols	No specific policies addressing vibration-induced hearing loss	More research on vibration's role in hearing loss, integration of vibration monitoring into HCPs
Palmer et al. (2015)[28] UK, case-control study	General workforce across multiple industries	Hearing impairments and balance disorders increase the risk of workplace injury	Occupational health programmes fail to screen for auditory-vestibular dysfunctions	No specific regulations addressing balance disorders and work safety	Integration of vestibular and auditory screening into occupational health assessments
Landen et al. (2004)[26] USA, cross-sectional study	Sand and gravel mining industry	37% of workers had hearing impairment; poor hearing protection compliance	Many workers not enrolled in HCPs, despite high-risk exposure	MSHA noise exposure regulations mentioned, but inconsistently enforced	Stronger enforcement of noise control measures, improved education on hearing protection
Kim (2010)[27] Korea, review article	Various industries in Korea	NIHL is the most common occupational disease after musculoskeletal disorders	Workplace noise remains a major occupational hazard, despite regulatory improvements	Korean Occupational Safety and Health Act covers NIHL, but compliance varies	Systematic implementation of HCPs across industries
Shan et al. (2020)[7] USA, systematic review	General workforce, multiple sectors	Hearing loss linked to unemployment and job instability	Occupational hearing loss interventions often neglect employment impacts	WHO global disability statistics referenced	Workplace accommodations for workers with hearing loss, employer incentives for inclusion
Nelson et al. (2005)[16] global, risk assessment study	Various global industries	16% of disabling hearing loss worldwide is occupational	High burden in developing regions, weak noise control regulations	WHO occupational noise exposure guidelines referenced	Engineering controls to reduce noise exposure, global standardisation of HCPs
Lindblad et al. (2014)[31] Sweden, prospective study	Teachers, musicians, industrial workers	Even noise below regulatory limits may cause inner ear dysfunction	Standard audiograms fail to detect early auditory damage	No specific policies on subtle hearing dysfunctions	Expansion of hearing screening beyond pure-tone audiometry
Masterson et al. (2015)[30] USA, longitudinal study	Various industries, 30-year hearing loss trends	Decline in overall ONIHL, but persistent high prevalence in mining and construction	Hearing loss risk remains high in certain industries, despite regulations	NIOSH and OSHA standards referenced	More targeted interventions in high-risk sectors, continuous monitoring

HCP: hearing conservation programme, HPD: hearing protection device, MHSC: Mine Health and Safety Council, MSHA: Mine Safety and Health Administration, NIOSH: National Institute for Occupational Safety and Health, NIHL: noise-induced hearing loss, ONIHL: occupational noise-induced hearing loss, OSHA: Occupational Safety and Health Administration, WHO: World Health Organization

middle ear resonance and absorbance.[11] Workers with middle ear disorders may be at an increased risk of developing ONIHL, as CHL can affect sound transmission, potentially leading to misdiagnosis and inappropriate interventions.[11,29] Evidence suggests that noise exposure below regulatory limits may cause inner ear dysfunction, affecting cochlear processing and leading to tinnitus and other auditory problems.[31] A more nuanced understanding of hearing conservation is needed; current noise regulations focus primarily on high-decibel exposure, without considering subtle damage occurring at lower noise levels.[29] Hearing impairments and balance disorders increase the risk of workplace injury.[8]

Theme 2: Gaps in HCPs

Hearing conservation programmes often focus on the outer ear and neglect middle ear conditions.[2,3] Many HCPs focus primarily on ONIHL and neglect middle ear disorders, leading to gaps in prevention, early detection, and treatment.[2,17] Routine screening for middle ear dysfunction is rarely incorporated into workplace audiological assessments, leading to underdiagnosis of conditions that may influence susceptibility to ONIHL.[11,14] Hearing protection device compliance remains a challenge, particularly among workers with middle ear pathologies who may find HPDs uncomfortable or ineffective.[15] Some industries lack comprehensive and standardised HCPs, particularly in LMICs where enforcement of occupational health regulations is inconsistent.[8,16] The implementation of comprehensive HCPs that include middle ear screening may be challenged by shortages of trained audiologists, high equipment costs, and limited workplace health infrastructure. In such contexts, task-sharing with primary healthcare providers, deployment of mobile screening units, and inclusion of basic otoscopy in worker examinations could serve as interim strategies to improve feasibility of hearing health interventions.

Theme 3: Policy and regulatory frameworks

Several studies mention the existence of occupational health guidelines and regulations, e.g. the National Institute for Occupational Safety and Health (NIOSH), WHO, and Mine Health and Safety Council (MHSC); however, there is often inconsistent enforcement and compliance with these regulations. Occupational noise regulations, such as those set by NIOSH, the Occupational Safety and Health Administration (OSHA), and the WHO, focus primarily on noise exposure limits and HPD use, without sufficient consideration of middle ear health.[4,30] Variability in HCP implementation and enforcement across industries and countries leads to inconsistent protection for workers. For example, the mining and construction industries have persistently high prevalences of ONIHL, despite regulations.[26,30] There is limited integration of balance and vestibular assessments into occupational health programmes, despite evidence that auditory-vestibular dysfunction contributes to workplace injuries,[28] especially in high-risk industries like mining and construction. Therefore, incorporating vestibular assessments into workplace screenings may improve occupational safety and reduce worker compensation claims.[27] Economic factors influence policy effectiveness, with workers in LMICs often lacking access to screening and intervention measures, including those for middle ear disorders,[14] due to resource constraints.[7,16]

Theme 4: Recommendations for occupational hearing health

Several recommendations emerged from this theme. First, integration of routine middle ear screening into HCPs is key. Studies recommend expanding audiological assessments to screening for middle ear disorders, ensuring that both conductive and sensorineural hearing impairments are assessed.[3,14] Comprehensive multicomponent HCPs that include noise control measures, regular hearing tests that incorporate tympanometry, and hearing protection should be implemented.[15,32] Second, the use of diagnostic tools such as wideband tympanometry are recommended .for the early detection of hearing damage.[3,11] Third, engineering noise control solutions should be prioritised over reliance on HPDs to provide long-term ONIHL prevention.[8,17] Fourth, personalised risk assessments based on individual susceptibility, including pre-existing middle ear conditions, should be integrated into workplace health programmes.[15,18] Fifth, stronger enforcement of workplace noise regulations is needed, particularly in high-risk industries such as mining and construction.[30] Sixth, longitudinal monitoring and early intervention programmes should be implemented.[18] Seventh, workplace accommodations for workers with hearing loss should be improved, including employer incentives for disability-inclusive workplace policies that ensure accessibility, provide reasonable accommodations, and reduce stigma – alongside the provision of assistive listening devices.[7] Education and awareness campaigns about the risks of noise exposure should be provided for workers.[29] Last, further research should be conducted on the interplay between ONIHL and middle ear disorders, the role of vibration in hearing loss, and the effectiveness of various intervention strategies.[3,4,26,29]

DISCUSSION

Knowledge gaps in middle ear disorders and ONIHL

Gaps in research on middle ear disorders in occupational settings were a key finding in this review, particularly in LMICs. While ONIHL has been extensively studied, only a few studies specifically addressed middle ear pathologies in noise-exposed workers.[3,11] This underlines the diagnostic limitations of current hearing conservation practices, which often rely solely on pure tone audiometry without consideration for middle ear screening. As a result, middle ear disorders may go undetected, leading to misdiagnosis or underestimation of hearing loss severity in workers with both ONIHL and conductive hearing impairment.

Regulatory and policy disparities between HICs and LMICs

The geographical distribution of studies highlights that regulatory approaches vary substantially between HICs and LMICs. While HICs have well-established occupational noise exposure regulations, such as OSHA and NIOSH standards in the USA, and EU noise directives in Europe, African LMICs often lack comprehensive occupational noise policies or struggle with enforcement and compliance.[4,16] For example, HICs enforce mandatory baseline testing, employer accountability, and advanced technologies such as electronic dosimetry, while African LMICs face significant enforcement and resource challenges. Additionally, studies in Africa show that policies primarily address ONIHL, without adequate screening for middle ear disorders.[3,14]

Industry-specific risks and understudied sectors

There is a need for industry-specific interventions. While mining and manufacturing remain high-risk sectors, the review identified other industries where ONIHL and conductive hearing loss overlap. Shipyard workers and metal industry employees were reported to experience complex interactions between CHL and ONIHL, requiring different intervention strategies than those used in other industries.[29,32] While ONIHL risks from chronic exposure to lower-level

noise have been studied, e.g. in teachers and musicians, similar studies are lacking in LMICs.[31] Vibration exposure was identified as an independent risk factor for hearing loss, yet it is rarely assessed in standard HCPs.[32]

Under-representation of African research and local contexts

Despite a disproportionate burden of ONIHL and middle ear disorders, Africa remains under-represented in primary occupational health research. Most region-specific contributions are limited to reviews and policy documents, rather than large-scale empirical, population-based research. There is also limited longitudinal research on the progression of ONIHL in African workers, making it difficult to assess the long-term effectiveness of HCPs. The influence of environmental factors, healthcare infrastructure, and economic constraints on occupational hearing health in Africa remains underexplored.

Overlooked role of middle ear pathologies in HCPs

An important finding from this review is that middle ear pathologies, such as chronic otitis media and tympanic membrane perforations, are prevalent among noise-exposed workers, yet these pathologies are rarely integrated into occupational health frameworks.[3,11] Research from Turkey and South Korea suggests that chronic noise exposure affects middle ear resonance and absorbance, potentially compounding hearing loss severity.[11,29] In Africa, middle ear infections remain widespread due to poor healthcare access, untreated infections, and environmental conditions, exacerbating hearing impairment in occupational settings.[14,33] Unlike in HICs, where early detection and treatment of middle ear disorders are integrated into occupational health screening, many African workers do not have access to routine otological assessments, leading to delayed diagnosis and worsening outcomes.[16,33] Additionally, HIV-positive workers may experience higher rates of middle ear infections and eustachian tube dysfunction, leading to an increased risk of CHL. These combined factors may contribute to greater occupational functional limitations, affecting job performance and safety; however, occupational health screenings rarely address these multiple risk factors simultaneously.[19] In LMICs, the lack of coordinated occupational health services results in workers seeking care only when hearing loss is advanced, thereby limiting the effectiveness of interventions. This reinforces a reactive rather than proactive approach to hearing healthcare in occupational settings.[7,8,34]

In HICs such as the USA and UK, HCPs are highly regulated, requiring routine audiometric testing, noise exposure monitoring, and worker education.[28,30] For example, in the USA, the OSHA and NIOSH enforce noise monitoring, baseline audiograms, and employer accountability.[4,30] Similarly, the European Union enforces directives on physical agents (including noise), which include mandatory employer responsibilities for risk assessment and engineering controls. In contrast, many African LMICs lack mandatory baseline testing, formal follow-up procedures, and/or penalties for non-compliance. Furthermore, HICs have begun to integrate technological advances, such as electronic dosimetry and individualised hearing risk tracking, which are not available in resource-limited settings. In Africa, HCPs are often poorly enforced or non-existent in informal industries, leaving workers vulnerable to hearing loss.[4] Where HCPs are implemented, they rarely incorporate middle ear assessments such as tympanometry, wideband absorbance testing, or vestibular evaluations, which could enhance early detection of middle ear disorders and appropriate intervention.[3,11,31]

Barriers to HPD use and compliance

Compliance with the use of HCPs remains a challenge in both HICs and LMICs. Studies suggest that, in LMICs, workers often reject HPDs due to discomfort, lack of awareness, and perceptions that they interfere with communication and job performance.[15,26] This is compounded in workers with pre-existing middle ear disorders, as standard HPDs may exacerbate ear pain or worsen symptoms of eustachian tube dysfunction.[29] In contrast, HICs are increasingly using personalised hearing protection solutions, such as custom-moulded earplugs and electronic noise-cancelling devices, to improve comfort and compliance.[18] African LMICs would benefit from similar innovations, but cost and accessibility remain significant barriers.[19]

There are significant disparities in policy enforcement between HICs and LMICs, regarding ONIHL prevention and management. In countries such as the USA, UK, and South Korea, strict occupational noise regulations mandate noise exposure monitoring, employer responsibility for protective measures, and regular audiometric surveillance.[27,30] In contrast, many African LMICs either lack robust occupational health regulations or fail to enforce existing policies.[4,8] A key policy gap in LMICs is the lack of integration between occupational health and general healthcare systems, which limits worker access to audiological and otological assessments.[3,14] There is limited coordination between government agencies, industries, and healthcare providers, resulting in fragmented implementation of hearing conservation efforts.[16,19] Economic constraints also influence policy effectiveness, particularly in LMICs where employers may resist costly interventions, and workers may prioritise job security over personal health.[7,35] This is in stark contrast to HICs, where government-funded initiatives and worker compensation schemes provide incentives for compliance.[16,26] For example, in countries such as Denmark and Canada, national health systems cover routine hearing screenings and middle ear assessments as part of occupational medical surveillance.[28,30,31] These comparative examples reveal a gap, not only in regulatory enforcement, but also in resource availability and policy commitment to hearing health.

Recommendations for integrating ONIHL and middle ear management

Recommendations for a comprehensive approach to occupational hearing health to enhance ONIHL prevention and middle ear disorder management, in Africa and similar LMICs, are proposed. First, audiological assessments in occupational settings should include middle ear evaluations (e.g. tympanometry, wideband absorbance, and vestibular screening) in addition to standard audiometry.[3,11] Second, occupational noise regulations should be strongly enforced.[16,30] Third, worker education and training on hearing loss prevention, focusing on HPD use, early symptoms of hearing impairment, and the importance of medical check-ups should be mandatory.[15,17] Fourth, cost-effective noise control solutions should be developed, prioritising engineering interventions over reliance on HPDs.[8,18] Finally, occupational health policies must evolve towards a more integrated preventive model, linking hearing conservation efforts with broader health system interventions – including the management of middle ear disorders and chronic infections such as HIV.[4,28]

Critical observations of the included studies

There was substantial variability in the study designs and quality of the articles reviewed. While systematic reviews and longitudinal studies provided strong evidence of noise exposure trends and HCP

impact, several of the cross-sectional studies had small sample sizes or limited generalisability to African workplaces. Few studies considered middle ear disorders as a primary outcome, and those that did were often based on highly specific populations (e.g. mineworkers from a single company or geographical region). Most studies from HICs emphasised sensorineural outcomes and did not account for co-morbid factors such as HIV. These limitations highlight the need for contextualised, multi-factorial research in the region.

Figure 1 illustrates the interaction of occupational noise exposure, middle ear pathology, and systemic health risks in African LMICs. Barriers to effective hearing conservation and practical intervention across clinical, policy, and infrastructural domains are indicated.

CONCLUSION

This review synthesised the interaction between sensorineural and conductive hearing loss in African workplaces, highlighting the under-recognised role of middle ear disorders in undermining the effectiveness of HCPs. While global literature has extensively documented ONIHL, this review is among the first to systematically interrogate how middle ear pathologies – especially common in immunocompromised and under-resourced populations – complicate diagnosis, intervention, and prevention efforts in occupational health contexts.

The findings highlight the need for a paradigm shift in hearing conservation in LMICs, particularly in Africa. In high-risk industries such as mining, construction, and manufacturing, workers are routinely exposed to excessive noise without adequate protection or access to comprehensive audiological and otological care. Most HCPs focus exclusively on ONIHL, failing to screen for, or manage, middle ear pathologies, resulting in missed opportunities for early intervention and rehabilitation.

To strengthen occupational hearing health systems, we propose the following: 1) integrating middle ear assessments into routine occupational health screenings, 2) reinforcing regulatory frameworks and enforcement mechanisms to align with international noise exposure standards, 3) expanding worker education to promote early detection and HPD compliance, 4) investing in engineering noise control solutions at source, and 5) designing contextually appropriate, cost-effective hearing conservation strategies. These must also account for high HIV prevalence in regions like South Africa, where immunosuppression exacerbates middle ear disorders. Addressing the intersection of noise exposure, infectious disease, and structural gaps in occupational health systems is key to a more effective and inclusive hearing conservation model.

Limitations

Despite its comprehensive scope, this narrative review has several limitations. First, it relied on the published literature, which may have introduced publication bias, as studies with significant or positive findings are more likely to be published than those with null or inconclusive results. Additionally, data availability on middle ear disorders in occupational settings remains limited, particularly in Africa, where research on hearing conservation often focuses solely on ONIHL. While the number of studies reviewed was relatively small, this was offset by a detailed, thematic and critical analysis that prioritised contextual relevance over volume. Future research should prioritise empirical work that simultaneously addresses noise exposure and middle ear disorders in African workplaces. Another limitation was the absence of large-scale longitudinal studies in Africa on the interplay between ONIHL and middle ear disorders, which limits the ability to draw conclusions about causality and long-term occupational hearing health trends. Furthermore, differences in regulatory frameworks across regions make direct comparisons between HICs and LMICs challenging. Many of the policy

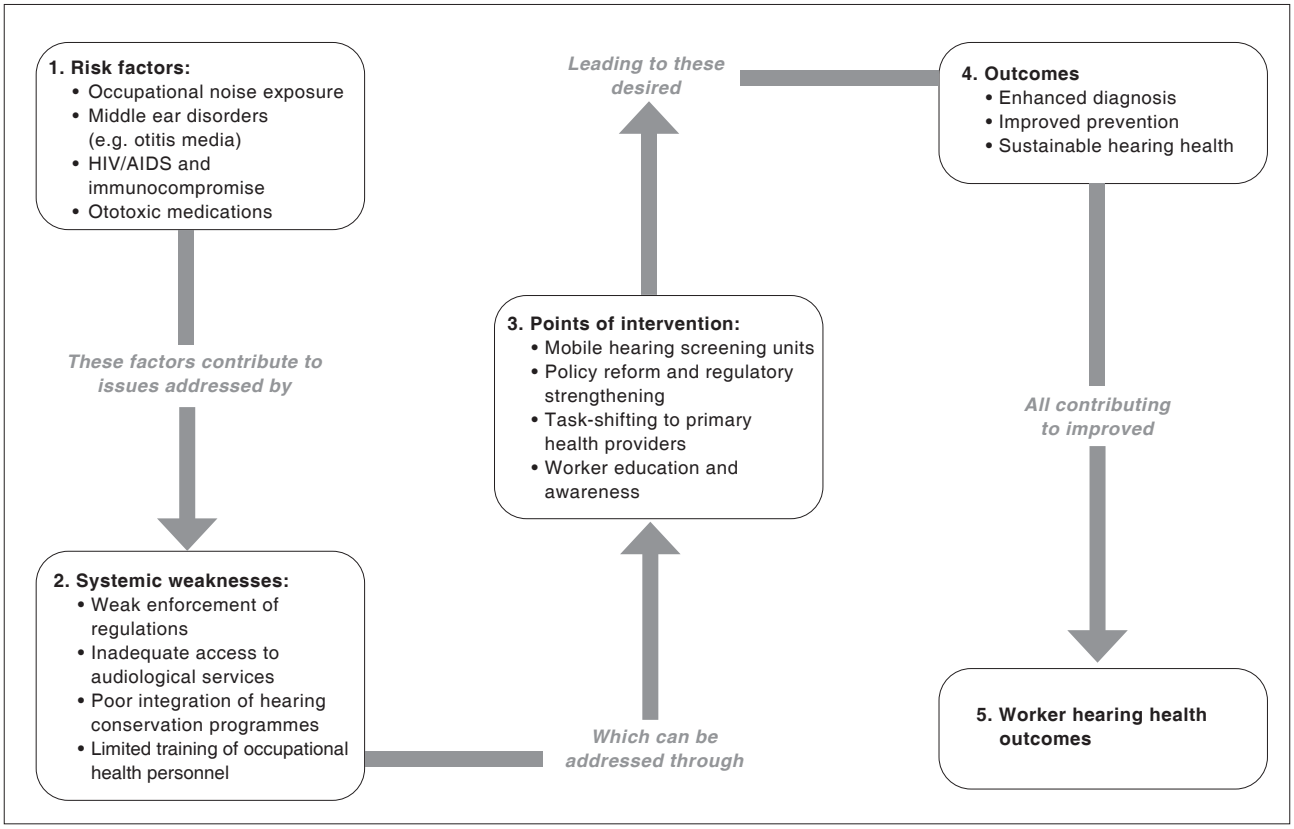

Figure 1. Conceptual framework for integrated occupational hearing conservation in African LMICs

recommendations and interventions that are effective in HICs may not be directly transferable to African LMICs without considering economic, infrastructural, and healthcare system constraints. For example, in HICs, hearing loss compensation programmes and regular workplace audiological screenings are mandated, whereas in many African LMICs, employers and workers alike may lack the resources or awareness to prioritise hearing health. Creating policy frameworks that incentivise noise control at the industry level, while providing low-cost hearing interventions for workers, is crucial. Finally, this review did not include primary data collection or meta-analysis, which limits its ability to assess quantitatively the magnitude of ONIHL and middle ear disorders in occupational settings. Future research should focus on longitudinal, population-based studies in LMICs, examining the combined effects of occupational noise exposure and middle ear pathologies, as well as the effectiveness of integrated hearing conservation interventions.

KEY MESSAGES

1. Middle ear disorders – often undetected due to the absence of otological screening – undermine the diagnostic accuracy and functional outcomes of HCPs. There is a need for an expanded audiological assessment and a multidisciplinary approach to hearing conservation, which include middle ear assessments.
2. Systemic challenges in LMICs, including weak regulatory enforcement, high HIV prevalence, and limited access to audiological services, exacerbate the risk and impact of occupational hearing loss.
3. A multidisciplinary, context-responsive approach is essential, combining expanded audiological assessment, policy reform, worker education, and cost-effective noise control interventions.

DECLARATIONS

The authors declare that this is their own work; all the sources used in this paper have been duly acknowledged and there are no conflicts of interest.

Authors' contributions

Both authors conceptualised the study, conducted the research and analysis, and wrote the manuscript.

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