

Occupational noise and vibration hazards: A narrative review of characteristics, health effects, assessment methods, and prevention strategies

Otitolaiye VO^{†1}, Omer F^{†1}, Mahfud R¹, Abdelrahim R¹, Kozhiparambath L¹, Elbadri H¹, Al-Bahri A¹

¹Department of Health, Safety and Environmental Management, International College of Engineering and Management, Oman.

† These authors contributed equally to this work and share first authorship.

ABSTRACT

Corresponding author:

Victor Olabode Otitolaiye,
Lecturer,
Department of Health, Safety and
Environmental Management, International
College of Engineering, 111 Seeb St, Seeb,
Oman

E-mail: victorlaye@yahoo.com

Tel.: +968 24 512000

ORCID ID: <https://orcid.org/0000-0001-9110-999X>

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Introduction: Occupational noise and vibration are common physical hazards across many industries and are associated with substantial auditory, musculoskeletal, vascular, neurological, and other non-auditory health effects. This narrative review integrates current evidence to support recognition, assessment, and prevention of these hazards in workplace settings.

Methods: A narrative review approach was adopted, consistent with established narrative-review guidelines and SANRA criteria. Literature searches in major databases focused on occupational noise, hand-arm and whole-body vibration, health outcomes, exposure assessment, and prevention. Peer-reviewed studies, reviews, and authoritative guidelines were included if they addressed exposure characterization, auditory or non-auditory and musculoskeletal or neurovascular health effects, assessment methods or standards, or engineering, administrative, and personal protective controls. Evidence was synthesized thematically without formal risk-of-bias assessment or meta-analysis.

Results: The review indicates that hazardous noise and vibration exposures remain widespread and contribute to noise-induced hearing loss, cardiovascular and psychological disorders, hand-arm vibration syndrome, low back pain, and other musculoskeletal and neurovascular conditions. Assessment commonly uses time-weighted or equivalent continuous sound levels for noise and frequency-weighted acceleration metrics for vibration, in accordance with international standards and regulations. Multiple engineering, administrative, and personal protective measures are available, but fully integrated workplace programs are still limited.

Conclusion: This review provides an occupationally focused framework to strengthen the systematic management of combined noise and vibration hazards.

Keywords: Noise, Vibration, Occupational health, Hazard assessment, Control strategies

Introduction

Noise and vibration are common physical hazards in workplaces, especially in industrial sectors such as manufacturing, construction, mining, and transportation.¹ Both hazards originate from

mechanical energy, but they vary in how they are transmitted, their health impacts, and regulatory aspects.² Occupational noise exposure is still widespread, with recent systematic reviews

showing that many workers around the world face dangerous noise levels, which raises the risk of hearing loss and other health problems.³⁻⁵ Prolonged exposure to high noise levels is a major cause of noise-induced hearing loss and has been linked to heart, metabolic, and mental health issues.^{3,6,7}

Similarly, occupational vibration exposure—whether transmitted through the hands and arms or the whole body—has been linked to a range of adverse health effects, including musculoskeletal pain, vascular and neurological disorders, and increased risk of disability.⁸⁻¹⁰ Epidemiological evidence demonstrates that both hand-arm vibration and whole-body vibration exposures are common in many workplaces and can result in significant morbidity if not properly managed.^{8,9} Rapid mechanization, the introduction of new technologies, and evolving production demands mean that many workers continue to experience combined or sequential exposure to noise and vibration, often in the same work shift or task.¹¹

Regulatory bodies and professional organizations have responded by developing exposure limits and technical standards, such as ISO 5349 for HAV, ISO 2631 for WBV, and the European Directive 2003/10/EC for noise and 2002/44/EC for vibration, alongside guidance from the World Health Organization and national authorities.¹²⁻¹⁵ Advances in measurement technologies, digital dosimetry, and modelling have improved the characterization of exposure profiles, while a broad range of engineering, administrative, and personal protective interventions have been proposed to control risk.^{16,17} Nevertheless, evidence remains fragmented: noise and vibration are often addressed separately, many studies are cross-sectional, and relatively few have evaluated comprehensive prevention programs that

integrate exposure assessment with tailored control strategies at the workplace level.^{10,18}

This narrative review aims to synthesize current evidence on occupational noise and vibration hazards with an explicit focus on their characteristics, health effects, assessment methods, and prevention strategies in workplace settings. Specifically, we seek to: (1) describe the main exposure metrics and regulatory benchmarks for noise, HAV, and WBV; (2) summarize the auditory and non-auditory, as well as musculoskeletal and neurovascular, health outcomes associated with these exposures; (3) review methods and tools used to identify and assess noise and vibration hazards; and (4) outline evidence-based control and prevention strategies, structured around the hierarchy of controls. By integrating scientific findings with key standards and guidelines, the review aims to provide a practical, occupation-focused framework to support the recognition, assessment, and management of noise and vibration hazards across diverse work environments.

Methods

This narrative review synthesized evidence on occupational noise and vibration, focusing on exposure, health effects, assessment, and control strategies. The review followed established narrative review guidelines, including those of Baethge et al., and aligned with the Scale for the Assessment of Narrative Review Articles (SANRA).¹⁹

Literature searches in Scopus and Google Scholar (mainly from 2000 onwards) combined terms for occupational noise and vibration (e.g. “occupational noise”, “hand-arm vibration”, “whole-body vibration”), health outcomes (e.g. “noise-induced hearing loss”, “cardiovascular”, “musculoskeletal disorders”, “hand-arm

vibration syndrome”), exposure assessment (e.g. “exposure assessment”, “ISO 5349”, “ISO 2631”), and prevention (e.g. “control strategies”, “hearing conservation”, “vibration reduction”). Peer-reviewed studies, reviews, and authoritative guidelines or reports (e.g. WHO, ISO, EU, national agencies) were included if they addressed at least one of four domains: (1) classification or quantification of occupational noise and/or vibration; (2) auditory or non-auditory, musculoskeletal, vascular, or neurological health outcomes; (3) exposure assessment methods or standards; or (4) engineering, administrative, or personal protective controls.

We excluded studies on purely environmental (non-occupational) community noise, animal

Results

Noise

Noise is defined as any form of undesirable sound that is perceived as loud, disruptive, and unpleasant to listeners.²⁰ It is also considered a subjective perception determined by the magnitude, characteristics, duration, and timing of sounds.²¹ On the other hand, sound is any form of energy typically generated by mechanical vibrations (produced by structural systems in equilibrium) and heard by humans.²² For example, vibrations arising from sources such as tuning forks, birdsong, beautiful melodies, and loud traffic are all considered sounds. Other major sources of dangerous noise include machinery and equipment in the workplace.²³

The World Health Organization (WHO) defines noise as any sound that exceeds 30–40 weighted decibels (dBA), depending on the environment, region, and time of day.²⁴ Above these thresholds, noise can result in numerous long-term or short-term health challenges, ranging from cardiovascular effects, sleep disruptions, low

experiments without clear occupational relevance, and non-English articles. Titles and abstracts were screened for relevance, followed by full-text assessment; reference lists of key papers and guidelines were hand-searched for additional studies. Owing to heterogeneity in study designs and outcomes, findings were synthesized narratively in thematic sections on noise, vibration, assessment, and prevention, with summary tables highlighting representative studies on identification, assessment, and management of these hazards. No formal risk-of-bias assessment or meta-analysis was conducted, and evidence selection reflects the author’s judgement, consistent with the narrative-review approach.

productivity, and hearing loss.²⁴ Over the years, noise has become an increasingly challenging source of environmental nuisance. Unwanted sounds can have severe effects on the physical, mental, and occupational safety of workers in any workplace or environment.²⁵ Hence, it is critical to examine the sources, characteristics, and hazards for effective noise management and control strategies.

Characteristics and Hazard Levels

In occupational settings, noise is typically characterized by its sound pressure level, frequency content, temporal pattern, and duration of exposure.^{26–28} Sound pressure level is expressed in decibels using A-weighting [dB(A)], which approximates the frequency sensitivity of the human ear and is widely used for workplace compliance assessments.^{27,28} Frequency content determines whether noise is perceived as low-, mid-, or high-pitched and influences both the risk of hearing damage and annoyance, while

temporal pattern distinguishes continuous, fluctuating, intermittent, and impulse noise.^{26,28}

Hazard levels are usually evaluated using the time-weighted average (TWA) or equivalent continuous sound level (LAeq) over a reference period, commonly an 8-hour working day.^{3,24} Many occupational guidelines define 85 dB(A) as the typical action level for daily noise exposure, above which the risk of noise-induced hearing loss increases substantially, and hearing-conservation measures are required.^{3,24} Peak sound pressure levels and the presence of strong impulsive components (e.g. from impact tools or explosions) can further increase risk, even when daily averages are similar.^{3,24} In practice, a full characterization of workplace noise hazards therefore requires consideration of level, frequency spectrum, temporal pattern, and exposure duration, rather than sound intensity alone.^{3,24}

Health Effects of Noise

Noise exposure is associated with a broad spectrum of adverse health effects, which can be classified into auditory and non-auditory outcomes. The most direct and well-established consequence is noise-induced hearing loss (NIHL), resulting from damage to cochlear hair cells from prolonged or intense exposure to sound levels typically exceeding 85 dB(A). The underlying mechanisms involve mechanical trauma, oxidative stress, and inflammatory responses within the cochlea, leading to irreversible loss of auditory function.⁶ Additionally, chronic noise exposure can result in tinnitus and speech discrimination difficulties, which significantly impair quality of life.⁶

Beyond auditory effects, noise exposure contributes substantially to non-auditory health outcomes. Epidemiological studies have

consistently demonstrated that chronic exposure to environmental and occupational noise increases the risk of cardiovascular diseases, including hypertension, coronary heart disease, and myocardial infarction.^{3,29} For example, individuals exposed to high noise levels have a 34% increased risk of cardiovascular disease and a 12% increase in cardiovascular mortality.³ The pathophysiology involves activation of the sympathetic nervous system and endocrine responses, resulting in elevated stress hormone levels, increased blood pressure, and vascular dysfunction.⁷

Noise also exerts significant effects on mental health and cognitive functioning. Chronic exposure is linked to increased prevalence of sleep disturbances, annoyance, anxiety, depression, and impaired cognitive performance.^{30,31} Sleep disruption, in particular, exacerbates fatigue, reduces work efficiency, and increases the risk of accidents. In children, noise exposure has been linked with behavioral problems and learning difficulties.³⁰

There is also emerging evidence that noise exposure may contribute to metabolic disorders, adverse reproductive outcomes, and impaired immune function, further underscoring its broad impact on human health.^{3,32} The severity of health effects depends on factors such as noise intensity, frequency, duration of exposure, and individual susceptibility. The following section focuses on identifying and assessing noise hazards and conditions in industrial settings. This approach is essential for understanding risk levels and implementing effective strategies to protect worker health and safety.

Identifying and Assessing Noise Hazards

In the past, exposure to high noise levels and their effects was limited to workers in selected occupations such as millers, blacksmiths,

stonemasons, and boilermakers. However, exposure to high noise levels is now commonly considered a workplace hazard occasioned by health and safety reforms in the industrial sectors worldwide. Likewise, the significant differences in noise features (such as sound volume, spectral content, intermittency, and impulsiveness) have prompted the need to identify and assess their hazardous nature in such work environments.

These transformations have been necessitated by the rising prevalence of workplace noise and resulting cases of noise-induced hearing loss (NIHL) caused by the rapid mechanization of industrial processes. However, other occupational hazards can cause hearing loss besides noise. For example, selected chemicals (used either alone or in conjunction with noise or other compounds) in industrial processes can cause ototoxicity. Solvents (such as toluene, styrene, ethylbenzene, and trichloroethylene), asphyxiants (such as carbon monoxide, hydrogen cyanide, and acrylonitrile), heavy metals (such as mercury, lead, and tin), and polychlorinated biphenyls are the four main groups of ototoxic substances.

Therefore, several studies have highlighted the instruments used to measure noise levels, hearing capacity, and effects, as well as to mitigate their consequences, although these instruments were only made available in the early 20th century. During this epoch, initial studies identified the characteristic “notch” in hearing sensitivity at 4000 Hz. In addition, these research studies identified frequency, intensity, and duration of exposure as key factors influencing the degree of hearing loss.^{33,34} Due to the variability in hearing risks, which depend on the unique acoustic properties of the exposure, damage-risk criteria have also been developed based on studies of continuous noise levels to ensure accuracy or ease of measurement.

It is now possible to precisely categorize noise based on several factors due to advancements in measurement technology, which go beyond defining “hazardous noise” solely by sound intensity. The review of the literature indicates that the strategies typically employed for noise hazard control and management are broadly classified into three groups: identification, assessment, and management, as shown in Figure . Table 1 presents an overview of strategies proposed over the last 20 years for identifying, assessing, and managing noise hazards in the workplace.

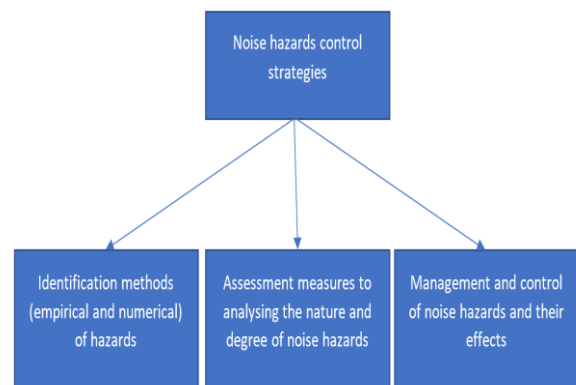


Figure 1: Classification of strategies for noise hazards control and management.

Noise Control Strategies

One of the most important techniques for controlling hazards is ranking or prioritization. The likelihood of an incident, accident, or sickness occurring, as well as the employee exposure, is typically considered when determining priority. The ranking or action list is usually established by prioritizing the risks. However, the degree of risk cannot be measured directly, as a single strategy is not applicable in all circumstances. Therefore, the most effective approach in each circumstance should be determined by employers who understand workplace operations and the seriousness of the situation, enabling objective judgments when ranking risks. In addition, each

hazard must be examined to determine its risk level using selected criteria. For example, the product information/manufacturer documentation, past experiences/research studies, and legislated requirements and/or applicable standards are critical. Other criteria include the use of industry codes, such as best practices and health hazards, as well as safety materials, such as safety data sheets.

At the workplace level, effective noise control relies primarily on engineering measures at the source and along the transmission path, such as equipment selection and maintenance, enclosure and isolation of noisy machinery, acoustic treatments of walls and ceilings, and optimized facility layout to separate noisy processes from quieter work areas.^{33,34} Administrative controls, including job rotation, scheduling noisy tasks, and limiting time in high-noise zones, can further reduce exposure when engineering controls alone are insufficient.^{33,34} Hearing conservation programs that combine regular noise surveys, fit-tested hearing protection, worker training, and audiometric surveillance are essential components of long-term NIHL prevention.^{33,34}

Implementing noise-control strategies can address the challenges posed by noise pollution. However, the design, development, and implementation of such strategies also require periodic assessment of

their effects on human health and occupational safety in the workplace. One such measure is the evaluation of hearing loss prevention programs.^{33,34} Continuous or irregular exposure to noise causes occupational noise-induced hearing loss (NIHL), which manifests gradually over time. However, this differs from occupational acoustic trauma, characterized by rapid hearing loss following a single exposure to loud, abrupt, or explosive sounds.^{4,33} Hence, NIHL is regarded as one of the most common workplace problems across various sectors.^{4,33}

A hierarchy of controls that favors engineering controls over administrative controls and personal protective equipment can help prevent occupational hearing loss.^{4,33,34} With the cooperation of management, industrial hygiene, engineering, and human resources, occupational/environmental medicine departments, along with the OEM physician, can prevent hearing loss using established safety programs and elements.^{4,33,34} Furthermore, the OEM physician could recommend audiometric testing to identify hearing loss and to document cases of permanent hearing loss in accordance with established safety guidelines.^{4,33} Lastly, the OEM physician must ensure employers establish proper controls and regular performance audits to prevent hearing loss among employees.^{4,34}

Table 1: Summary of major studies on the identification, assessment, and management of noise hazards

References	Study objectives	Code	Assessment method proposed	Major findings
Yaoyuenyong and Nanthavanij ³⁵	To examine the optimal workforce without noise hazard exposure in the workplace	A	Proposed 4 solution algorithms (i.e., three approximations and one exact) to determine a minimum number of workers and their work assignments to attend noisy workstations without noise hazard exposure.	The findings showed that the hybrid procedure outperformed all four algorithms (when utilized separately) and can find an optimal solution for 88% of the test problems. In addition, it was observed that daily noise exposure should not exceed 90 dBA.
Asawarungsaengkul and	To design and develop an optimal and cost-effective	A	Proposed, developed, and applied an analytical design strategy comprising six optimization models to	The models successfully determined a suitable set of noise controls to reduce or eliminate the noise levels to which workers are exposed daily,

Nanthavan ij ³⁶	strategy for noise hazard control.		determine optimal control strategies for noise hazards in industrial facilities without exceeding the budget.	ensuring they remain below permissible levels.
Bernat ³⁷	To examine the level of awareness of noise hazards and the value of soundscapes in national parks	A	The study employed a questionnaire approach to examine potential noise threats to park users and adjoining resources, as well as the quality of soundscapes, to assess the potential for conservation. Also, semantically based differential and descriptive methods were adopted to examine how students perceive the quality of the soundscape in the parks.	The results showed that the national parks are characterized by diverse and unique soundscapes due to pressure from road traffic and tourism, resulting in noise hazards. Hence, the study concluded that the acoustic values of the parks need to be preserved.
Śliwiński ³⁸	To examine the degree of ultrasonic-based noise hazards in workplace environments.	A	The study employed the qualitative methods and case study approach to examine the ultrasonic noise hazards.	The study highlighted the current challenges associated with the measurement procedures and the interpretation of results critical to assessing ultrasonic noise hazards and their impact on the human body. Also, the study highlighted the procedures for assessing audible noise and their applications in the ultrasonic range.
Kozłowski, Młyński and Adamczyk ³⁹	To examine the impulse noise hazard and application of hearing protection devices in workplaces that utilize forging hammers.	A	Employed empirical measurements to examine the impact of impulse noise on the health and safety of workers in the industry. Also, the effect of using earplugs or earmuffs was examined as a potential protective measure to safeguard workers' hearing. Lastly, the study examined the impact of hearing protection devices using an acoustical test fixture rather than subject testing.	The findings highlight the potential to examine the impact of tested earplugs or hearing devices, such as earmuffs, as protective measures to safeguard workers in workplaces that utilize forge hammers.
Ibhadode, Oyedepo, Ogunro, Azeta, Solomon, Umanah, Apeh and Ayoola ⁴⁰	To examine the level of exposure of humans to aircraft noise hazards around selected airports in Nigeria.	A	The physical measurements of aircraft and environmental noise parameters were conducted using the integrated CR811C Noise meter. The study also employed 120 periodic noise-sampling surveys at selected locations around the 4 selected airports in Nigeria.	The results showed extremely high measured physical parameter values that significantly exceed the WHO Recommended Maximum Noise levels of 35 dB (A) to 55 dB (A) for indoor and outdoor, respectively. Hence, the study finds that such noise levels can impair speech intelligibility, cause noise annoyance, and disrupt sleep.
Moore, Chavez, Narang, Bogle and Stern ⁴¹	To examine the impact of noise hazards during laser lithotripsy based on the gold standard holmium YAG	A	The study employed mixed methods, including intraoperative noise measurements obtained during ureteroscopy and laser lithotripsy from cases using both TFL and holmium lasers. As well as questionnaires distributed	The findings showed that the noise levels from 16 TFL and 15 holmium laser lithotripsy cases were comparable. However, significantly higher noise levels were recorded during holmium lithotripsy, ranging from 3.1 dB to 4.3 dB. The questionnaire results showed that the

	laser and novel thulium fiber laser.		postoperatively to operating room (OR) staff.	OR staff reported that lower noise levels are required for concentration, communication, and task completion with the TFL. Overall, it was observed that the TFL produced 3.1-4.3 dB less noise than the holmium laser.
Kompala and Lipowczan ⁴²	To identify and examine the impact of noise hazards on populated areas near functional roadway frontier crossings	I	The study employed questionnaires to identify potential noise hazards at Schengen border crossings near Poland with other nations, which stretch 3,500 km and include 200 Polish border crossings.	The findings indicate that the noise associated with functional border crossings is hazardous to the inhabitants of bordering areas. The noise emanating from such crossings was found to exceed the maximum permissible levels. Since these areas are near the borders, it is critical to identify and examine the nature, sources, and extent of the noise. The questionnaire results revealed that the residents consider the noise a problem, which requires deploying future preventive steps.
Batko and Stepien ⁴³	To estimate the uncertainty in the environmental noise hazard (ENH) indices using non-parametric methods.	I	Proposed non-standard procedures to estimate ENH based on the standard deviation estimation of the average results.	Findings highlighted three types of estimators, namely: kernel, unbiased and maximum likelihood, and their usefulness as potential non-parametric estimators for ENH.
Wei, Wang and Lee ⁴⁴	To successfully predict and visualize BIM-based construction noise hazards for improving occupational safety and health awareness.	I	Proposed a building information modelling (BIM) framework for construction safety, training, and analysis.	The study highlighted the potential application of the BIM framework for the prediction and visualization of noise hazards during safety training in the construction industry. The framework was able to reasonably predict and visualize the spatial distribution of noise in BIM using scattered data recovered from wearable noise sensors.
Cavallari, Garza, DiFrancesco, Dugan and Walker ⁴⁵	To develop and implement a noise-hazard scheme for road maintenance operations.	M	The study proposed and developed noise reduction ratings for hearing protection devices (HPD) using noise-monitoring results. The noise-hazard scheme was developed and applied to the task and equipment used during brush cutting.	The findings indicate that the developed worker-designed noise-hazard scheme breaks down and simplifies the identification of noise levels. It also aids in the assessment of noise hazards and recommends the most appropriate HPD for workers.

A - Assessment; I - Identification; M - Management

Vibration Hazards

Vibration in occupational environments refers to mechanical oscillations or repetitive motions transmitted from machinery, tools, or vehicles to the human body, typically through direct contact or through supporting surfaces.^{8,46} These oscillations are characterized by parameters such as frequency, amplitude, and direction, which together determine the magnitude and nature of exposure for workers.⁴⁶ In industrial settings, vibration hazards are generally classified into two main categories: hand-arm vibration (HAV) and whole-body vibration (WBV). HAV arises from the use of powered hand tools and equipment, such as grinders, chainsaws, and drills, which transfer vibratory energy to workers' hands and arms. WBV, by contrast, occurs when the entire body is exposed to vibration through seats or floors, particularly during the operation of heavy vehicles or industrial machinery.^{8,47}

Both HAV and WBV are recognized as significant physical hazards in sectors such as construction, manufacturing, mining, and agriculture, where the prevalence of vibrating equipment is high, and the risk of exposure is substantial. Despite their widespread occurrence, awareness and systematic management of vibration hazards can be limited in some industries, underscoring the need for robust identification and control strategies. Therefore, a clear understanding of the fundamental characteristics and hazard levels of workplace vibration is essential for accurately assessing risks and implementing effective preventive measures. The following section examines the key characteristics and hazard levels associated with occupational vibration.

Characteristics and Hazard Levels

Vibration in occupational environments is characterized by several physical parameters,

most notably frequency (measured in hertz, Hz), amplitude (expressed as acceleration in meters per second squared, m/s^2), and the direction or axis of transmission (x, y, and z axes).^{8,9} The nature of vibration exposure depends on whether it is hand-arm vibration (HAV), typically transmitted through the hands and arms during the use of powered tools, or whole-body vibration (WBV), which affects the entire body when operating heavy machinery or vehicles.⁹

Measurement of occupational vibration exposure is standardized by international guidelines, such as ISO 5349 for HAV and ISO 2631 for WBV. Vibration is quantified using accelerometers that record frequency-weighted root mean square (r.m.s.) acceleration values. For HAV, daily exposure is calculated as the root-sum-of-squares of the frequency-weighted accelerations along the three axes, resulting in a normalized eight-hour exposure value ($A(8)$, in m/s^2). For WBV, the highest value among the three axes is considered, with multiplying factors applied to account for differences in risk.⁹

Regulatory standards, including the EU Directive 2002/44/EC, define hazard levels through exposure action values and exposure limit values. For HAV, the action value is $2.5 m/s^2 A(8)$, and the limit value is $5.0 m/s^2 A(8)$. For WBV, the action value is $0.5 m/s^2 A(8)$, and the limit value is $1.15 m/s^2 A(8)$. Exposures above these thresholds require employers to implement control measures to reduce risk (HSA, 2007). The actual hazard posed by vibration depends on measured acceleration, exposure duration and pattern, posture, grip force, tool maintenance, and environmental conditions such as cold and wetness, which can exacerbate effects.⁹ A clear understanding of these characteristics and hazard levels is essential for accurate risk assessment and

the development of effective prevention strategies in the workplace.

Health Effects of Vibration Hazard

Occupational exposure to vibration, whether through the hands and arms (hand-arm vibration) or the whole body (whole-body vibration), is associated with a variety of adverse health outcomes affecting the vascular, neurological, and musculoskeletal systems. Hand-arm vibration (HAV), commonly experienced by workers using powered tools such as grinders, drills, and chainsaws, can lead to hand-arm vibration syndrome (HAVS). HAVS is characterized by symptoms such as blanching and numbness of the fingers (vibration white finger), tingling, reduced grip strength, and diminished manual dexterity. These effects are primarily due to vascular and neurological damage resulting from prolonged exposure to vibration, and in severe cases, symptoms may become permanent and disabling.⁸

Whole-body vibration (WBV), typically encountered by operators of heavy vehicles and machinery in industries such as construction and agriculture, has been strongly linked to lower back pain, spinal degeneration, and lumbar musculoskeletal disorders. Chronic exposure to WBV can also contribute to headaches, fatigue, sleep disturbances, and visual or gastrointestinal complaints. The risk and severity of these health effects depend on factors such as the magnitude, frequency, and duration of vibration exposure, as well as individual susceptibility and work practices.^{8,9} The HAV and WBV exposures may also exacerbate other ergonomic and occupational hazards, increasing the risk of disability and lost workdays. Early identification, regular health surveillance, and the implementation of effective control measures are essential to prevent the

progression of vibration-related disorders and to protect worker health and productivity.^{9,48}

Identifying and Assessing Vibration Hazards

The process of identifying and assessing vibration hazards in occupational settings requires a systematic evaluation of both the sources and the extent of worker exposure. Initially, all equipment and machinery that generate significant vibration, such as powered hand tools, industrial vehicles, and heavy machinery, should be identified, with particular attention to whether the exposure is classified as hand-arm vibration (HAV) or whole-body vibration (WBV).^{8,9} Measurement of vibration exposure is typically performed using triaxial accelerometers following established standards, such as ISO 5349-1 for HAV and ISO 2631-1 for WBV, which specify the methods for capturing frequency-weighted root mean square (r.m.s.) acceleration along the x, y, and z axes.^{9,48}

The daily exposure value, A(8), is calculated to normalize exposure over an eight-hour reference period, enabling direct comparison with regulatory thresholds. For example, the European Directive 2002/44/EC specifies action values of 2.5 m/s² and 0.5 m/s², and limit values of 5.0 m/s² and 1.15 m/s², for HAV and WBV, respectively.^{8,9} Risk assessment involves comparing measured A(8) values to these benchmarks, while considering additional factors such as exposure duration, tool maintenance, environmental conditions, and individual susceptibility. Detailed documentation of findings, including sources, exposure levels, and affected workers, ensures that vibration hazards are managed effectively and in compliance with current occupational health standards.⁴⁸

Vibration Control Strategies

The development and implementation of vibration reduction and control strategies could

help address the problems associated with HAV, WBV, and other vibration-related ailments suffered by workers. Potential strategies for controlling vibration hazards in the workplace can be addressed in three steps, as illustrated in Figure .

One such measure will be the development of legal standards for vibration hazards and

addressing their impacts in the workplace. According to OSM, there are currently no legal guidelines for vibration hazards⁴⁷, which typically include identification, assessment or management/control. This observation is particularly evident in sectors such as agriculture, where legal regulations for the use of vibrating tools have not been widely documented in the literature.

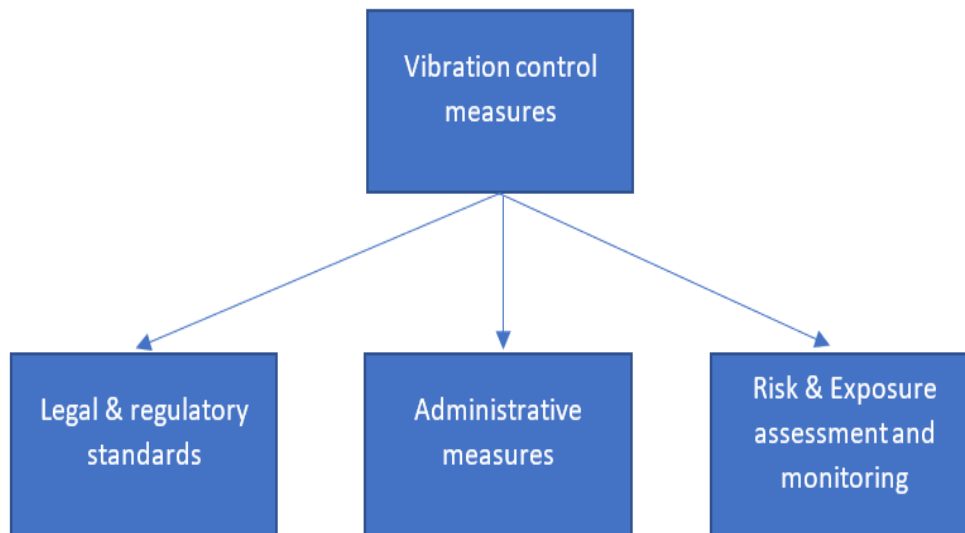


Figure 2: Classification of strategies for noise hazards control and management in the workplace.

Furthermore, the establishment of administrative control measures by companies will go a long way toward eliminating or reducing the vibration hazards workers are exposed to. Administrative control measures can define the job duration, equipment used, and the duration and intensity of workers' exposure. In addition, such measures will identify and highlight high-risk tools and processes and ensure their maintenance. Furthermore, the measures will propose the proper selection, purchase, and utilization of low-

vibration tools to safeguard the health and safety of workers.

Lastly, monitoring and control measures will significantly help reduce vibration risks by defining and implementing health and safety measures. Early monitoring or reporting of the early signs and exposure symptoms of workers to vibration hazards could be addressed by such measures. These measures could help reduce the chronic effects of workplace vibrations. Table 2 presents an overview of major study findings on vibration hazards in the literature.

Table 2: Summary of major study findings on vibration hazards

References	Study objectives	Major findings
Starck ⁴⁹	To examine the impact of high impulse acceleration levels in hand-held vibratory tools as an important hazard factor for hand-arm vibration syndrome.	The findings showed that analysis of impulsiveness provides crucial data that could partially highlight the typically reported symptoms of vibration-induced white fingers. Furthermore, the study showed that the parameters for the impulsive vibration signal concur with the analysis of the short-time history.
Griffin ⁹	To compare the standardized methods used for estimating the hazards associated with whole-body vibration and repetitive shocks.	The study showed that the newly amended International Standards for assessing human exposure to vibration and shock will cause unnecessary confusion.
Griffin ⁴⁶	To examine the efficiency of gloves in lessening hand-transmitted vibration hazards.	The findings showed that the frequency weighting for hand-transmitted vibration advocated in British Standard 6842 (1987) and International Standard 5349 (1986) significantly enhances the evident isolation provided by gloves. This is because the gloves showed marginal effects on the vibration transmission to the hand from most of the tools.
Vlok, Coetzee, Banjevic, Jardine and Makis ⁵⁰	To develop an optimal decision framework for component replacement through vibration monitoring and the proportional-hazard-based model.	The study proposed a conditional maintenance policy based on histories collected over 2 years, with a comparison with current practices in operational plants. The case study describes the use of the Weibull proportional hazards model to determine the optimal replacement policy for a critical item subject to vibration monitoring.
Jetzer, Haydon and Reynolds ⁴⁸	To examine the impact of effective intervention in minimizing Hand-Arm Vibration Hazards in the Workplace.	These findings suggest that ergonomic intervention can be effective in controlling the workplace hazard of tool vibration using ergonomics, antivibration gloves, and medical surveillance (MS) strategies. The MS was used to determine and monitor hand-arm vibration syndrome (HAVS) and carpal tunnel syndrome (CTS).

Discussion

This narrative review confirms that occupational noise and vibration remain prevalent hazards across sectors such as manufacturing, construction, mining, transportation, and agriculture, despite long-standing regulatory limits and technical guidance.^{3,4} Recent evidence shows that large proportions of workers globally are still exposed to hazardous noise levels, contributing to a substantial burden of noise-induced hearing loss and related morbidity.^{4,5} Consistent with earlier work, the studies synthesized here demonstrate that chronic noise exposure is associated not only with NIHL and tinnitus but also with increased risks of

hypertension, coronary heart disease, cardiovascular mortality, metabolic disturbances, sleep disruption, and adverse mental health outcomes.^{3,6,7,30,31} Similarly, epidemiological and mechanistic studies indicate that hand-arm and whole-body vibration exposures at or above the action and limit values defined in ISO standards and the EU Directive 2002/44/EC are associated with hand-arm vibration syndrome, lower-back pain, spinal degeneration, and broader musculoskeletal and neurovascular disorders among exposed workers.⁸⁻¹⁰

The evidence compiled in this review also highlights significant advances in the identification, measurement, and modeling of noise and vibration hazards.^{33,34} Improvements in instrumentation, frequency-weighted metrics, and damage-risk criteria have enabled more accurate characterization of continuous, intermittent, and impulse noise, as well as HAV and WBV, and have informed the development of contemporary exposure standards.^{9,39,48} At the same time, numerous engineering and administrative interventions have been proposed and evaluated, including optimization algorithms for workforce allocation to noisy workstations,³⁵ analytical design strategies for cost-effective noise control,³⁶ building and acoustic design solutions,^{51,52} and structured hearing-conservation and vibration-reduction programs that integrate monitoring, worker training, and health surveillance.^{45,48} However, many of these interventions have been tested in specific industrial or regional contexts, often with limited follow-up, and relatively few studies have rigorously evaluated comprehensive programs that jointly address noise, vibration, and co-exposures such as ototoxic chemicals, ergonomics, and psychosocial stressors. Several important gaps in the current evidence base were identified. Many studies of health effects rely on cross-sectional designs, self-reported symptoms, or incomplete exposure histories, which constrain causal inference and hamper the estimation of dose-response relationships and latency periods for chronic outcomes.^{8,9} In addition, research remains unevenly distributed, with a concentration of detailed exposure and intervention studies in high-income countries, while low- and middle-income settings undergoing rapid mechanization may experience similar or greater risks, yet have fewer resources for monitoring and control.^{40,42}

Future work should therefore prioritize longitudinal and intervention studies that evaluate integrated noise and vibration control programs, employ modern technologies such as wearable sensors, digital dosimetry, and predictive analytics for real-time surveillance.⁴⁴ and explicitly investigate combined exposures and vulnerable worker groups. Strengthening this body of evidence will be essential for refining guidelines, supporting effective regulatory enforcement, and guiding the design of practical occupational health programs to prevent noise- and vibration-related disease. This article brings together evidence on occupational noise and vibration into an integrated, management-oriented framework, showing how combined exposures and non-auditory outcomes can be addressed through coordinated assessment methods and prevention strategies in modern workplaces.

Conclusion

Noise and vibration remain critical occupational hazards that frequently co-exist and interact in modern workplaces, posing significant risks to worker health, productivity, and quality of life. Effective management requires an integrated approach that recognizes the potential for combined exposures and leverages cross-disciplinary collaboration among employers, engineers, occupational health professionals, and policy makers. The implementation of evidence-based hazard identification, rigorous exposure assessment, and a hierarchy of engineering and administrative controls is essential for sustainable risk reduction. As industrial processes and technologies evolve, ongoing education, digital monitoring, and predictive risk analytics will play an increasingly important role in prevention. Furthermore, emerging research on the synergistic effects of noise and vibration, and on

their impact on mental health, highlights the need for continued surveillance and adaptive strategies. Fostering a culture of prevention and proactive risk management will help ensure safer, healthier workplaces amid ongoing industrial and technological change.

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