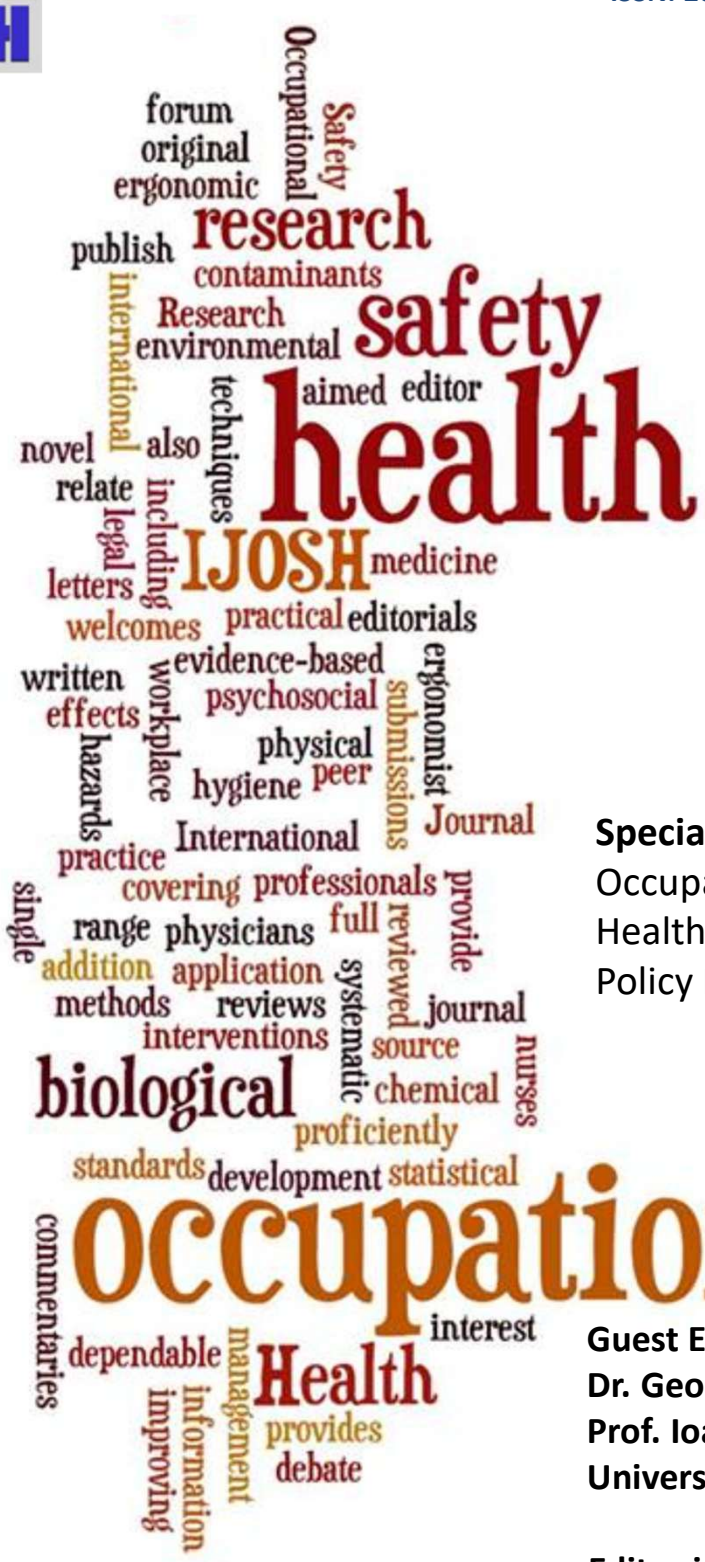
Journal website: http://www.nepjol.info/index.php/IJOSH/index
Official journal of the Occupational Health and Safety Society of Nepal

International Journal of Occupational Safety and Health

ISSN: 2091-0878 (Online) ISSN: 2738-9707 (Print)



Vol 16, No 1 (2026)

OPEN ACCESS

Special Issue:
Occupational and Environmental Health: Challenges, Innovations, and Policy Perspectives

Guest Editors:
Dr. Georgios Farantos, Triple PostDoc
Prof. Ioanna Damikouka
University of West Attica (UNIWA), Greece

Editor in Chief:
Prof Dr Sunil Kumar Joshi

DOAJ EBSCO Embase Google scholar INDEX COPERNICUS INTERNATIONAL Scopus

International Journal of Occupational Safety and Health

Vol 16, No 1 (2026)

ISSN: 2091-0878 (Online)
ISSN: 2738-9707 (Print)

CC BY NC

Journal website: http://www.nepjol.info/index.php/IJOSH/index
Official journal of the Occupational Health and Safety Society of Nepal

Table of Contents

Original Articles

DOAJ EBSCO Embase Google scholar INDEX COPERNICUS INTERNATIONAL Scopus

International Journal of Occupational Safety and Health

Vol 16, No 1 (2026)

ISSN: 2091-0878 (Online)
ISSN: 2738-9707 (Print)

CC BY NC

Table of Contents

Original Articles

Review Articles

Journal website: http://www.nepjol.info/index.php/IJOSH/index
Official journal of the Occupational Health and Safety Society of Nepal

DOAJ EBSCO Embase Google scholar INDEX COPERNICUS INTERNATIONAL Scopus

International Journal of
Occupational Safety and Health

Vol 16, No 1 (2026)

ISSN: 2091-0878 (Online)
ISSN: 2738-9707 (Print)

CC BY NC

Table of Contents

Review Articles

Case Study

Journal website: http://www.nepjol.info/index.php/IJOSH/index
Official journal of the Occupational Health and Safety Society of Nepal

DOAJ EBSCO Embase Google scholar INDEX COPERNICUS INTERNATIONAL Scopus

International Journal of Occupational Safety and Health

ISSN: 2091-0878 (Online) ISSN: 2738-9707 (Print)

Original Article

A pilot study approach on occupational disorders among metal craftsmen of Lalitpur, Nepal

Bhaila A[1,4], Joshi SK[2], Shigdel R[3], Ghosh T[4]

[1]Department of Physiology, KIST Medical College and Teaching Hospital, Lalitpur, Nepal

[2]Department of Community Medicine, Kathmandu Medical College and Teaching Hospital, Kathmandu, Nepal

[3]Department of Clinical Science, University of Bergen, Bergen, Norway

[4]Faculty of Health and Wellness, Sri Sri University, Cuttack, Odisha, India

Corresponding author:
Prof. (Dr.) Tirthankar Ghosh,
Dean, Ergonomics and Exercise Physiology Laboratory,
Faculty of Health and Wellness,
Sri Sri University, Cuttack,
Odisha 754006, India
E-mail: tirthag@gmail.com
ORCID ID: http://orcid.org/0000-0002-8953-5903

Date of submission: 03.09.2025
Date of acceptance: 05.02.2026
Date of publication: 05.04.2026

Conflicts of interest: None

DOI:https://doi.org/10.3126/ijosh.v16i1.80482

Copyright: This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License

ABSTRACT

Introduction: Metalcraft is a centuries-old tradition in Lalitpur, Nepal. Workers are exposed to various ergonomic and respiratory risks due to prolonged exposure to metal dust, fumes, and repetitive physical tasks. The present study aims to assess the pulmonary function and musculoskeletal complaints among metal craftsmen particularly involved in making sculptures.

Methods: A pilot cross-sectional study was conducted among 30 metal craftsmen purposively selected in Lalitpur Metropolitan City ward no. 6 and 17. Pulmonary Function Tests (PFT) were performed using a digital spirometer. Musculoskeletal discomfort was assessed using the standardized Nordic Musculoskeletal Questionnaire.

Results: 46.6% of metal craftsmen showed signs of respiratory disorders. Significant differences were found in % Predicted FEV1 and FEV1/FVC ratios ($p < 0.05$) between the different types of work in which metal craftsmen were involved. Lower back discomfort was the most common musculoskeletal complaint, but differences across work types and hours were not statistically significant.

Conclusion: Occupational exposure among metal craftsmen may contribute to respiratory impairment. Musculoskeletal issues, although reported, were not significantly associated with work type or duration in this pilot sample. Further research with a larger sample is warranted.

Keywords: Ergonomics, Metal craftsmen, Musculoskeletal Disorders, Nepal, Occupational Health, Spirometry.

Introduction

The ethnic Newar community of Nepal, particularly Kathmandu and Lalitpur, has been involved in making ancient metal sculptures for centuries. Brass, bronze, and various alloys are highly used materials for making numerous Buddhist or Hindu idols.[1] The process involves making a wax model of the desired statue and then casting it in metal. This technique requires precision and skill, and it takes several months to complete a single statue.[2] The involvement of strenuous, hand-intensive work increases the risk of upper limb musculoskeletal disorder

(MSD) among these metal craftsmen.[2] "Musculoskeletal disorders" include a wide range of inflammatory and degenerative conditions affecting the muscles, tendons, ligaments, joints, peripheral nerves, and supporting blood vessels.[3] These include clinical syndromes such as tendon inflammations and related conditions, nerve compression disorders (carpal tunnel syndrome, sciatica), and osteoarthrosis, as well as conditions such as myalgia, low back pain and other regional pain. Body regions most commonly involved are the lower back, neck, shoulder, forearm, and hand.[3] Work-related musculoskeletal disorders (WMSDs) represent a set of diseases affecting the muscles, nerves, tendons, ligaments, joints, synovial sacs, cartilage, fascia and spinal discs, which originate from and are aggravated by poor working conditions or by methods adopted while engaging in work tasks.[4] Work-related musculoskeletal disorders affecting the back, lower limbs, and especially upper limbs and neck, can be extremely costly if not addressed appropriately.[5] Highly repetitive jobs that require grabbing, repetitive wrist bending, vibration, and localized mechanical strain are thought to be contributing factors to the development MSD affecting upper limbs.[6] An occupational disease is any chronic ailment contracted primarily as a result of an exposure to risk factors arising from work activity (WHO).[7] Occupational health hazards of metal craftsmen often includes musculoskeletal pain including back pain, knee pain, joint pain and also suffer from respiratory trouble like asthma due to dust of metal.[7] The process of handicraft metal work uses hazardous industrial processes of high-temperature melting, foundry work, beating, grinding, and machining; similar to hazard-prone industrial processes. Craftsmen are exposed to serious occupational and ergonomics-based hazards.[8] Different metals may be correlated with occupational hazards (toxicity, heat stress, and fumes), route of entry (inhalation, skin contact, and ingestion) and phase of hazard.[8] As hammering is the most predominant activity in the entire work process of metal idol crafts, a large number of workers are engaged in this activity. Although metal craftwork has been practiced for many years, no such study of these works has been reported in Nepal so far. Thus, in the present study, the prevalence of upper limb MSD among these metal craftsmen engaged in strenuous, hand-intensive jobs will be evaluated. This study also evaluates the pulmonary function of these workers.

Methods

This cross-sectional pilot study aims to evaluate musculoskeletal disorders and pulmonary function among metal craftsmen working in different areas of Lalitpur Metropolitan City. The study period was between July and August 2025. The study targeted 30 traditional metal craftsmen (e.g., bronze, copper, or brass workers) working in small workshops or household units in Lalitpur district, a known hub for metal art and craftsmanship. Metal craftsmen of age group 25-50 years in Lalitpur Metropolitan City with at least 5 years of experience in the given field were included in the study. The study population included metal craftsmen from selected wards of Lalitpur Metropolitan City, purposively chosen based on the concentration of metal working activities and accessibility. Workers who gave written consent and with at least five years of experience were included in the study whereas, subjects with history of heart disease, chronic respiratory disease, recent thoraco-abdominal surgery, recent ophthalmic surgery and subjects with physical abnormalities were excluded from the study. The metal craftsmen were divided into three groups based on the types of work they do:

1. Detail work- engraving, fine carving, chiseling

2. High-heat work- melting metal, casting, welding

3. Finishing work- Polishing

Permission from each selected participant was obtained prior to the studies through written consent. The study has been approved by the Institutional Ethics Committee, Sri Sri University

(IEC/SSU/017-2024), and the Nepal Health Research Council (Ref. no. 2964).

This research data is primary data collected using the Nordic Body Map questionnaire to measure musculoskeletal disorder complaints. In addition, the demographic data collected included age, gender, work experience, work hours per week, and work break hours. Pulmonary Function test was performed using a spirometer ('MEDSPIROR' RMS recorder and medicare system, Chandigarh, India) between 9 a.m. and 12 p.m. Spirometry assessments were performed according to American Thoracic Society/European Respiratory Society standards. The spirometer is supplied with software that makes corrections for age, sex, weight, height, and ambient temperature to the given parameter. Subjects were instructed to take a deep breath and blow into the disposable mouthpiece as quickly and forcefully as possible. A nasal clip was applied over the nose to ensure breathing through the mouth alone. Subjects were instructed to press their lips tightly around the mouthpiece. Forced expiratory volume in one second (FEV1), forced vital capacity (FVC), FEV1/FVC, and peak expiratory flow rate (PEFR) were measured. The best of the three readings was considered for analysis. For normal lung function tests, predicted percentage of ≥ 80% for FVC and FEV1 and FEV1/FVC ratio of ≥ 0.7 were considered cut-off values. Obstructive lung function was defined as having FEV1 < 80% of predicted and FEV1/ FVC < 0.7 and restrictive lung function was defined as having FVC < 80% of predicted and FEV1/FVC ≥0.7.[9] Statistical analysis was done using Statistical Package for the Social Sciences SPSS v. 17. Descriptive statistics were used to analyze the demographic variables. Mean, standard deviation, frequency, and percentage were calculated. Student's t-tests and chi-square tests were used to determine significant differences between the parameters of two groups. A p-value less than 0.05 was considered statistically significant.

Results

Demographic variables related to the study population primarily including age, height, weight are presented in Table 1. All the participants in the study were men, age ranging 25-49 years with average work experience of 16.13 years. The working hours ranges 36-78 hours per week with a break of an hour per day.

The working posture of the metal craftsmen is long hours of repetitive, and awkward postures that include forward neck bending, stooped/bent-back posture, sitting on floor cross legged or squatting, repetitive wrist flexion/extension. According to questionnaire, musculoskeletal discomfort was prevalent among metal handicraftsmen. The findings indicated that lower back was the most frequently reported region of musculoskeletal discomfort as shown in Table 2.

Table 1: Demographics of the metal handicraft workers (n=30)

Variables	Metal Handicraft workers (M±SD)
Age (years)	36.96±8.02
Height (cm)	165±4.73
Weight (kg)	68.16±8.74
Duration of work per week (hours)	59.60±14.99
Duration of rest per day (hours	1
No. Of working days in a week	6
Working experience (in years)	16.13±7.69

Notes: M±SD, Mean and Standard Deviation

Figure 1: Working posture of metalcraftsmen

Table 2: Frequency of body region discomfort

Body Region	Frequency (%)
Lower Back	27 (90%)
Neck	10 (33.33%)
Wrists/Hands	9 (30%)
Knees	6 (20%)
Elbows	6 (20%)
Upper Back	4 (13.3%)
Shoulders	3 (10%)
Hips/Thighs	3 (10%)
Ankle	1 (3.33%)

Table 3: Pulmonary functions comparison among types of metal craftsmen

Parameter	Engraver (n = 20) Mean ± SD	Melting/Casting/Welding (n = 5) Mean ± SD	Polishing (n = 5) Mean ± SD
FEV1 (L)	2.98 ± 1.05	1.48 ± 0.86	3.29 ± 0.93
FVC (L)	3.65 ± 1.11	3.14 ± 0.95	3.88 ± 1.16
FEV1/FVC (%)	82.05 ± 13.12	55.85 ± 39.75	85.10 ± 4.99
% Predicted FEV1	91.04 ± 24.62	48.01 ± 27.35	89.05 ± 20.07
% Predicted FVC	96.29 ± 24.44	93.14 ± 41.17	87.61 ± 15.79
PEFR (L/min)	367.0 ± 145.2	278.8 ± 124.1	456.1 ± 131.8
FEF 25% (L/s)	4.83 ± 2.07	4.00 ± 1.62	5.35 ± 0.86
FEF 50% (L/s)	4.36 ± 1.48	3.14 ± 0.98	4.14 ± 0.93
FEF 75% (L/s)	2.71 ± 1.16	1.76 ± 0.50	2.90 ± 1.03

The study showed significantly lower FEV1, FVC, FEV1/FVC, % predicted FEV1 and % predicted FVC in workers who are involved in high heat and metal fume exposure type of work (melting metal, casting welding) as shown in Table 3. The study showed a significantly lower FEV1, FVC, FEV1/FVC, PEFR, FEF 25% and FEF 75% in workers with longer exposure of more than 15 years of working experience as shown in Table 4.

PFT parameters	Less than 15 years (Mean±SD)	More than 15 years (Mean±SD)	t value	df	p value
FEV1 (L)	3.54±0.785	2.299±1.052	3.701	27.995	0.001
FVC	4.13±0.839	3.247±1.114	2.477	27.999	0.020
FEV1/FVC (%)	86.218±5.587	73.778±23.945	2.070	18.236	0.053
% Predicted FEV1	93.996±16.489	77.951±32.515	1.760	24.828	0.091
%Predicted FVC	94.046±14.363	94.1981±32.515	-.018	23.681	0.986
PEFR (L/min)	446.323±127.166	317.059±135.631	2.680	26.767	0.012
FEF 25% (L/s)	5.699±1.570	4.154±1.771	2.524	27.312	0.018
FEF 50% (L/s)	4.62±1.549	3.788±1.112	1.645	20.890	0.115
FEF 75% (L/s)	3.087±1.163	2.261±0.936	2.094	22.648	0.048

Table 4: Pulmonary Functions comparison according to years of working experience

Discussion

The majority of workers reported experiencing pain and discomfort related to musculoskeletal disorders, with the lower back being the most commonly reported area of body pain, according to the results of the Standardized Nordic questionnaires, which are displayed in Table 2 for the analysis of musculoskeletal symptoms.

According to the study, workers are working in a forward-bending posture for extended periods of time without taking appropriate breaks throughout the day. These prolonged sitting and bending posture, can definitely cause musculoskeletal strains and negatively affect health.[10,11]

In a similar study done in India to evaluate the prevalence of upper limb musculoskeletal disorders among brass metal workers, it was found that that high repetitiveness, prolonged work activity (10.5 h of work per day with 8.4 h spent on hammering) and decreased handgrip strength may be causative factors in the occurrence of upper limb MSD.[2] A study done in India to assess the work-related musculoskeletal disorder among Goldsmiths found that these workers suffer from occupational disorders like pain at neck , shoulder, wrist, and low back and also eye problem like irritation and burning sensation.[12] These musculoskeletal issues also lower productivity at work.[13,14]

This study also evaluated the pulmonary functions of the metal craftsmen. We could not find any study which is previously done to assess pulmonary functions among metal craftsmen involved in making metal statues and sculptors.

A study conducted in Iran to assess respiratory health and cross-shift changes among foundry workers found that lung function values for FVC and FEV1 were significantly lower in the exposed group compared with the unexposed office workers group. [15] The majority of airborne pollutants, like dust and metal fumes, have been demonstrated to negatively impact exposed workers' lung function.[16]

In a study conducted in Malaysia to evaluate respiratory symptoms, spirometric lung patterns, and metal fume concentrations among welders, it was found that 60.71% of welders had normal lung function, followed by obstructive and restrictive, with 3.57% and 35.71%, respectively.[17] In the present study, the significantly lower PFT parameters, as shown in Table 2, were observed among workers in the melting metal, casting, and welding group, indicating a higher respiratory risk, likely attributable to prolonged exposure to metal fumes, high temperatures, and potentially inadequate respiratory protection. This highlights the need for improved occupational safety measures in these high-risk subgroups.

A significantly lower FEV1 in workers with longer exposure, as shown in Table 3, indicates a decline in lung function associated with chronic exposure to metalworking environments. Also, a significantly lower FVC suggests a reduction in the total air exhaled by long-term-exposed workers, which may imply restrictive or mixed-type impairments. A significant decline in PEFR indicates reduced expiratory power, potentially linked to obstructive airway diseases. A reduction in Forced Expiratory Flow at 25% of FVC reflects deterioration in small airway function with prolonged exposure. Reduction in FEF 75% indicates possible late-phase airway obstruction in long-term exposed individuals.

Conclusion

The findings highlight the occupational health risks faced by traditional metalworkers. The majority of metal craftsmen had WMSDs in different body regions, with lower backache being the most common. Also, the study found the decline in respiratory function parameters among the metal craftsmen.

Limitations

Under-reporting or over-reporting of symptoms due to factors like fear of job loss, or lack of awareness of their condition, was the major limitation of the study. Also, objective measurements (such as biomechanical analyses or workstation assessments) are not included in the study due to resource constraints or a lack of equipment, which may reduce the study's quality.

Ethical Consideration

Informed and written consent was obtained from all participants. Ethical clearance was also obtained from Sri Sri University and Nepal Health Research Council for the full-scale study.

Acknowledgement

We express our sincere gratitude to the craftsmen who rendered immense cooperation during the completion of this study.

References

1. Shakya S. The Metal Art in Nepal. Lumbinī Prabhā. 2019;4(1). Available from: https://www.academia.edu/43217223/The_metal_Art_in_Nepal_Sanjay_Shakya_Background
2. Gangopadhyay S, Ghosh T, Das T, Ghoshal G, Das BB. Prevalence of upper limb musculoskeletal disorders among brass metal workers in West Bengal, India. Industrial health. 2007;45(2):365-70. Available from: https://doi.org/10.2486/indhealth.45.365
3. Punnett L, Wegman DH. Work-related musculoskeletal disorders: the epidemiologic evidence and the debate. Journal of electromyography and kinesiology. 2004;14(1):13-23. Available from: https://doi.org/10.1016/j.jelekin.2003.09.015

4. Bispo LG, Moreno CF, de Oliveira Silva GH, de Albuquerque NL, da Silva JM. Risk factors for work-related musculoskeletal disorders: A study in the inner regions of Alagoas and Bahia. Safety Science. 2022;153:105804. Available from: https://doi.org/10.1016/j.ssci.2022.105804

5. Yassi A. Work-related musculoskeletal disorders. Current opinion in rheumatology. 2000;12(2):124-30. Available from: https://doi.org/10.1097/00002281-200003000-00006

6. Gangopadhyay S, Ray A, Das A, Das T, Ghoshal G, Banerjee P, Bagchi S. A study on upper extremity cumulative trauma disorder in different unorganised sectors of West Bengal, India. Journal of occupational health. 2003;45(6):351-7. Available from: https://doi.org/10.1539/joh.45.351

7. Ganguly M, Patsa MK, Ghosh A, Ganguly A. An insight to the bell metal industry of Bankura, West Bengal, India. Int. J. Life Sci. 2016;5(2):105-11. Available from: https://www.academia.edu/70624950/An_Insight_to_the_Bell_metal_Industry_of_Bankura_West_Bengal_India

8. Pati S. Evaluating Occupational Health and Safety (OHS) Issues for Craftsmen in Metal Handicrafts. Research into Design for a Connected World. Smart Innovation, systems and technologies, Volume 135. Springer Singapore. 2019:439-49. Available from: https://doi.org/10.1007/978-981-13-5977-4_37

9. Celli BR, MacNee WA, Agusti AA, Anzueto A, Berg B, Buist AS, et al. Standards for the diagnosis and treatment of patients with COPD: a summary of the ATS/ERS position paper. European Respiratory Journal. 2004;23(6):932-46. Available from: https://doi.org/10.1183/09031936.04.00014304

10. Rasoulivalajoozi M, Rasouli M, Cucuzzella C, Kwok TH. Prevalence of musculoskeletal disorders and postural analysis of beekeepers. International Journal of Industrial Ergonomics. 2023;98:103504. Available from: https://doi.org/10.1016/j.ergon.2023.103504

11. Demissie B, Bayih ET, Demmelash AA. A systematic review of work-related musculoskeletal disorders and risk factors among computer users. Heliyon. 2024;10(3):e25075. Available from: https://doi.org/10.1016/j.heliyon.2024.e25075

Ghosh T, Das B, Gangopadhyay S. Work-related musculoskeletal disorder: an occupational disorder of the goldsmiths in India. Indian journal of community medicine: official publication of Indian Association of Preventive & Social Medicine. 2010;35(2):321-5. Available from: https://doi.org/10.4103/0970-0218.66890

12. Bai Y, Kamarudin KM, Alli H. A systematic review of research on sitting and working furniture ergonomic from 2012 to 2022: Analysis of assessment approaches. Heliyon. 2024;10(7):e28384. Available from: https://doi.org/10.1016/j.heliyon.2024.e28384

13. Oestergaard AS, Smidt TF, Søgaard K, Sandal LF. Musculoskeletal disorders and perceived physical work demands among offshore wind industry technicians across different turbine sizes: A cross-sectional study. Int J Ind Ergon. 2022;88:103278. Available from: https://doi.org/10.1016/j.ergon.2022.103278

14. Saraei M, Masoudi H, Aminian O, Izadi N. Respiratory health and cross-shift changes of foundry workers in Iran. Tanaffos. 2018;17(4):285-90. Available from: https://pmc.ncbi.nlm.nih.gov/articles/PMC6534795/

15. Evaluation of impairment/disability secondary to respiratory disorders. American Thoracic Society. Am Rev Respir Dis. 1986;133(6):1205-9. Available from: https://cir.nii.ac.jp/crid/1571135650277253248

17. Bakri SF, Hariri A, Ismail M, Abdullah S, Kassim NI. Evaluation of respiratory symptoms, spirometric lung patterns and metal fume concentrations among welders in indoor air-conditioned building at Malaysia. International Journal of Integrated Engineering. 2018;10(5):109-21. Available from: https://doi.org/10.30880/ijie.2018.10.05.017

International Journal of Occupational Safety and Health

ISSN: 2091-0878 (Online) ISSN: 2738-9707 (Print)

Original Article

Bronchoalveolar lavage as a tool for assessing potential occupational exposure: a retrospective study

Karaiskos C[1], Kalkavouris N[1], Farantos G[1], Dounias G[1]

[1]Public Health Policy Department, University of West Attica, Athens, Greece.

Corresponding author:
Karaiskos Christos,
Public Health Policy Department, School of Public Health, University of West Attica, 196 Alexandras Av, 115 21 Athens, Greece
Email: ckaraiskos@uniwa.gr
Phone: 00306945174212
ORCID ID: https://orcid.org/0009-0001-0623-8453

Date of submission: 12.12.2025
Date of acceptance: 08.04.2026
Date of publication: 15.04.2026

Conflicts of interest: None

DOI:https://doi.org/10.3126/ijosh.v16i1.87351

Copyright: This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License

ABSTRACT

Introduction: Bronchoalveolar lavage (BAL) is a fundamental diagnostic procedure for evaluating diffuse parenchymal lung diseases (DPLDs). However, its diagnostic precision is critically dependent on the integration of a detailed occupational history. Occupational exposures are frequently overlooked in clinical practice, leading to potential misdiagnosis.

Methods: We conducted a retrospective analysis of 210 BAL samples from 207 patients over one calendar year at a tertiary referral hospital in Attica, Greece. Data regarding demographics, smoking status, and occupational history (classified via ISCO-08) were correlated with BAL cytology using descriptive statistics, χ^2 tests, t-tests, and one-way ANOVA with post-hoc comparisons. Missing data were supplemented through extensive record review and patient interviews.

Results: Occupational history was absent in 79.5% of initial clinician referrals. Upon data completion, 23.3% of patients were identified as active workers. Workers in the agricultural and forestry sector (ISCO-08 Group 6) showed significantly higher total BAL cell counts (P=0.025) and specific cytological patterns, including increased macrophages and mast cells. While smoking significantly altered differential counts, it did not influence the total cell count.

Conclusion: Specific BAL profiles are associated with certain occupational groups, yet a significant gap in history-taking persists. Systematic occupational assessment is mandatory to improve the diagnostic utility of BAL in respiratory medicine. These findings suggest that BAL can serve as a valuable 'sentinel tool' for occupational surveillance in respiratory medicine.

Keywords: Bronchoalveolar lavage, occupational exposure, ISCO-08, agricultural workers, lung diseases

Introduction

The diagnosis of diffuse parenchymal lung diseases (DPLDs) remains one of the most challenging areas in respiratory medicine. These conditions encompass a wide array of interstitial disorders, many of which are directly or indirectly caused by prolonged inhalation of hazardous environmental and occupational agents.[1,2] According to the Global Burden of Disease study, occupational exposures to organic and inorganic dusts, chemical fumes, and bioaerosols contribute significantly to the global prevalence of chronic respiratory morbidity and mortality.[3]

Bronchoalveolar lavage (BAL) has established itself as a cornerstone of the diagnostic workup of these diseases, offering a safe, minimally invasive method for sampling the distal airways and alveolar spaces.[4] By analyzing the cellular and

non-cellular components of the epithelial lining fluid, clinicians can gain valuable insights into the inflammatory and immunological processes occurring within the lung parenchyma. However, BAL findings arerarely pathognomonic and must be interpreted in the appropriate clinical context**.** For instance, a lymphocytic predominant pattern can be found in sarcoidosis, hypersensitivity pneumonitis, or certain drug-induced lung diseases.[5]

The clinical "gold standard" for interpreting BAL results is the integration of cytological data with a meticulous clinical and occupational history. In the absence of such history, specific findings—such as the presence of mast cells or certain inorganic particles—may be overlooked or misinterpreted, leading to the erroneous classification of occupational diseases as "idiopathic".[6] Despite the critical importance of this information, occupational history-taking is often neglected in the fast-paced environment of tertiary care hospitals.

This study seeks to address this gap by quantifying the extent of underreporting of occupational data in a specialized respiratory setting in Greece. Furthermore, by utilizing the International Standard Classification of Occupations (ISCO-08), we aimed to investigate whether specific labor sectors exhibit characteristic "BAL signatures" that could assist in the early identification of work-related lung injury, even when clinical symptoms are non-specific.

Methods

We conducted a retrospective analysis of all patients who underwent BAL for diagnostic purposes at a tertiary general hospital in the Attica region over a continuous 12-month period. The hospital serves as a major referral center for complex respiratory cases in Greece. A total of 210 BAL samples were collected from 207 patients. The study received ethical approval from the Institutional Review Board, and all data were anonymized to protect patient confidentiality. The study and the telephone interview protocol were approved by the Scientific Council of the General Hospital of Attica (Approval No. 31 ΗΔ/25, 2025).

Recognizing the limitations of existing medical records, a comprehensive data retrieval protocol was implemented:

1. Laboratory Archives: Retrieval of the primary cytological reports, including total nucleated cell counts (TNCC) and differential cell counts.
2. Clinical Referrals: Examination of the original request forms submitted by the referring pulmonologists.
3. Medical Records: Review of inpatient and outpatient files, including discharge summaries and admission notes.
4. Confirmatory Interviews**:** When occupational or smoking data were missing or ambiguous (which was the case for the majority of the cohort), telephone interviews were conducted with the patients or their primary caregivers using a structured questionnaire focusing on lifetime work history and environmental exposures. Missing occupational data were supplemented through 173 confirmatory telephone interviews. Verbal informed consent was obtained from all participants after explaining the study's scope. BAL recovery was considered adequate if >40% of the instilled volume was retrieved with minimal bronchial epithelial contamination (<5%). The structured questionnaire used for the telephone interviews was developed specifically for this study and included standardized questions regarding current occupation, longest-held occupation, duration of employment, and potential exposure to organic, inorganic, and chemical agents throughout the patient’s working life.

To ensure international comparability, occupations were classified using the ISCO-08 system. This hierarchical structure allowed us to group patients based on the nature of their work and potential exposure profiles. We focused on the "Major Groups" of the ISCO-08 to maintain statistical power. Patients who had retired many

years prior but had a significant lifetime exposure in a specific sector were classified based on their primary long-term occupation.

Figure 1 illustrates the flow of BAL sample collection, patient inclusion, and completion of occupational history data.

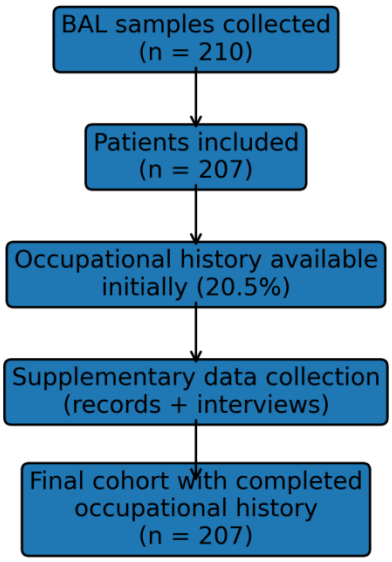


Figure 1: Study flow diagram and occupational data completion process

BAL was performed by instilling sterile saline (typically 3 X 50 mL) into a wedge position of a segmental bronchus. The fluid was recovered by gentle suction. Total nucleated cell counts were determined using a hemocytometer. Differential cell counts (macrophages, lymphocytes, neutrophils, eosinophils, and mast cells) were performed on Cytospin preparations stained with May-Grünwald-Giemsa, with at least 500 cells counted per slide. The presence of specialized cells (e.g., siderophages, foamy cells) and foreign particles (e.g., asbestos fibers) was also documented.

Data were analyzed using SPSS (version 24.0). Descriptive statistics were used for demographic variables. Continuous variables were expressed as mean ± standard deviation (SD). Differences between occupational groups were assessed using independent-samples t-tests and a one-way ANOVA with post hoc Tukey tests for multiple comparisons. Categorical variables were compared using the x^2 test. A P-value of <0.05 was considered statistically significant.

Results

The most striking initial result was the lack of documentation. On the initial clinician referral forms, occupational history was completely absent in 79.5% of cases. Even when records were searched, the information was often vague (e.g., "worker" or "private employee"). Through our supplemental retrieval process, we successfully classified the occupations of 100% of the cohort. Following the supplemental retrieval strategy and confirmatory interviews, the occupational classification success rate reached 100% for the study cohort.

The cohort comprised 207 patients, with a mean age of 64.9 ± 14.08 years. Regarding their status at the time of the procedure, 23.3% were active workers, 40.0% were retired, 12.4% were engaged in domestic work, and 4.3% were unemployed. The distribution across ISCO-08 groups is detailed in Table 1.

A significant association was found between occupational category and BAL cellularity.

Group 6 (Agricultural and Forestry workers) emerged as a distinct subgroup with the highest inflammatory markers in the lung.

Table 1: Detailed Distribution of Patients by ISCO-08 Occupational Category (N=207)

ISCO-08 Group	Occupational Description	N	Percentage (%)
1 & 4	Managers and Clerical Support	14	6.7%
2	Professionals (Engineers, Scientists, Doctors)	30	14.3%
3	Technicians and Associate Professionals	14	6.7%
5	Service and Sales Workers	26	12.4%
6	Agricultural, Livestock, Forestry, and Fishery	18	8.6%
7	Craft and Related Trades Workers	14	6.7%
8	Plant and Machine Operators, Assemblers	20	9.5%
9	Elementary Occupations (Unskilled Laborers)	19	9.0%
N/A	Domestic Work / Retired / Unemployed	52	26.1%

Table 2: Comparison of Total BAL Cell Counts (TNCC) across Occupational Groups

Comparison: Group 6 (Agriculture) vs.	**Mean Difference in TNCC (10^6 cells)**	**P-value**
Group 2 (Professionals)	Higher in Group 6	0.025
Group 5 (Service Workers)	Higher in Group 6	0.008
Group 7 (Craft/Trades)	Higher in Group 6	0.002
Group 8 (Machine Operators)	Higher in Group 6	0.026
Group 9 (Elementary Occ.)	Higher in Group 6	0.035

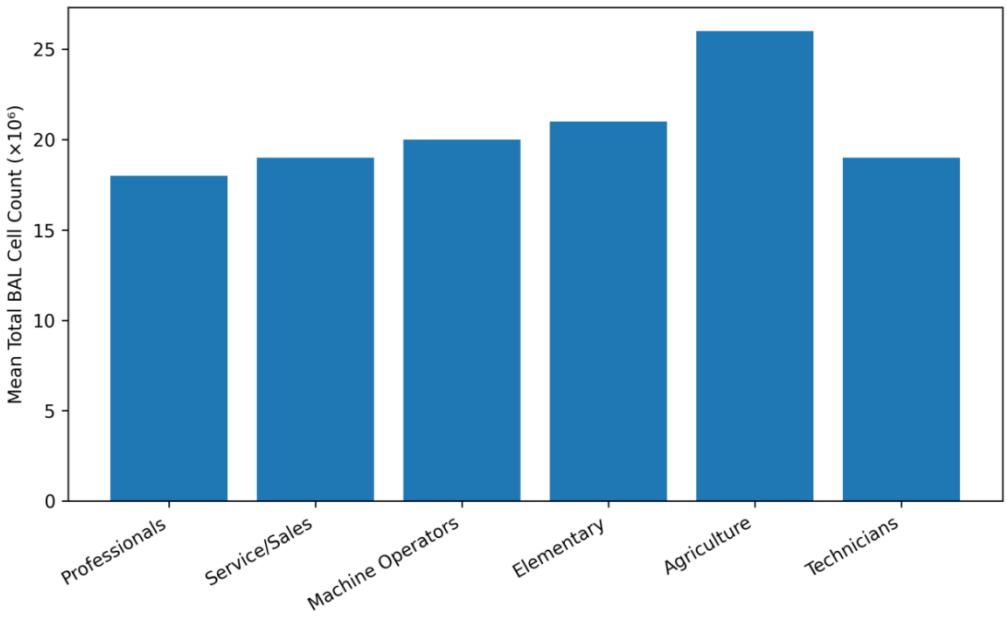
As shown in Figure 2, the mean total BAL cell count differed across ISCO-08 major occupational groups, with the highest values observed in Group 6 (Agriculture).

In addition to the total cell count, the differential analysis showed that agricultural workers had a unique combination of elevated macrophages and mast cells. Specifically, the presence of mast cells—often a marker of hypersensitivity

reactions to organic dusts—was significantly more frequent in this group compared to the "cleaner" professional environments of Group 2. Agricultural workers (Group 6) exhibited higher mast cell percentages and greater total BAL cellularity than other occupational groups, suggesting a distinct inflammatory pattern in this sector.

Given the high prevalence of smoking in the Greek population, we analyzed its impact. Active smokers (24.8%) and former smokers (22.4%) showed distinct patterns: smokers had higher macrophage counts, while former smokers showed neutrophil predominance. Interestingly, while Group 6 workers were among the heaviest smokers (highest mean pack-years), there was no statistical correlation between smoking status and the total cell count.

This suggests that the increased total cellularity in agricultural workers is a direct result of occupational exposure rather than tobacco use. Pearson correlation analysis showed no significant association between smoking pack-years and total nucleated cell count ($r = 0.12$, $P = 0.45$), indicating that occupational exposure, rather than smoking, was the primary driver of TNCC elevation in Group 6.



Discussion

The results of this study highlight a profound systemic weakness in the diagnostic workup of respiratory diseases: the neglect of occupational history. Similar occupational health challenges have been documented across different industries worldwide, including aquaculture and food processing sectors.[6,7] In nearly 80% of our cases, the clinician failed to record the patient's occupation, effectively "blinding" the cytologist. This persistent underreporting of occupational history—evidenced by the 79.5% rate of missing data in the initial referrals—likely reflects practical constraints in routine clinical practice, including time constraints during patient consultations and limited training of clinicians in occupational risk assessment. This finding is consistent with international literature suggesting that occupational history is the most frequently omitted part of the medical record.[8,9]These findings should be interpreted as exploratory and hypothesis-generating, rather than as evidence of causal relationships or individual-level exposure assessment.

The diagnostic consequences of this omission are significant. Our findings demonstrate that different occupations lead to different "biological footprints" in the lungs. The Agricultural and

Forestry group (ISCO-08 Group 6) showed a consistent pattern of high cellularity and increased mast cells. This cytological signature is strongly associated with chronic exposure to organic dusts, endotoxins, and fungal spores—common in livestock farming and agriculture.[10] The elevated mast cell count in agricultural workers likely reflects an immune response to organic dust and fungal antigens, such as Saccharopolyspora rectivirgula, which are known to trigger hypersensitivity pathways.[10] Such patients are at high risk for conditions like "Farmer's Lung" or Organic Dust Toxic Syndrome (ODTS). Without an occupational context, a high cell count might be dismissed as non-specific inflammation or attributed solely to smoking.[11] Although Group 6 exhibited the most pronounced cytological alterations, modest increases in total cellularity were also observed in Groups 7 (Craft and Related Trades Workers) and 8 (Plant and Machine Operators), suggesting that industrial and mechanical occupational environments may also contribute to inflammatory BAL profiles, albeit to a lesser extent.

Our data, however, suggest that the total BAL cell count may serve as an independent indicator of occupational exposure. While smoking shifts the *proportions* of cells (more macrophages or neutrophils), the *absolute volume* of cellular infiltration appears to be driven by the work environment. This is a critical distinction for the clinician. If a patient presents with a very high total cell count, the suspicion for an occupational etiology should be high, regardless of their smoking status.

Furthermore, we identified inorganic particles (such as asbestos) in a small but significant percentage of patients (1.67%). In these cases, the BAL provided definitive evidence of exposure that was not initially reported by the patient. These findings underscore the potential role of BAL not only as a diagnostic procedure but also as a sentinel tool for occupational health surveillance.[12]

The integration of the ISCO-08 system proved to be an effective framework for this analysis. By standardizing the way we categorize work, we can begin to build a database of "normal" and "pathological" BAL ranges for specific industries. This would move BAL interpretation from a subjective assessment to a more data-driven, objective diagnostic process.

Future prospective studies with larger occupational subgroups are required to validate these associations using multivariable analytical approaches. From a practical standpoint, the implementation of a short structured occupational checklist within referral forms—mandating documentation of current occupation, longest-held occupation, and classification according to ISCO-08 major groups—could substantially reduce underreporting and enhance the diagnostic interpretation of BAL findings.

As a retrospective study, we were limited by the quality of the original records, although our 173 confirmatory telephone interviews mitigated this significantly. However, the retrospective design precludes definitive causal inferences, and potential recall bias from these interviews must be acknowledged. Additionally, the sample size in certain ISCO-08 groups was small, which may have limited our ability to detect more subtle cytological differences between industrial sectors or to perform robust multivariable regression models. Given the limited number of participants within individual ISCO-08 major groups, formal multivariable regression modeling was not statistically appropriate and could have resulted in model overfitting. Future prospective studies are needed to further control for non-occupational confounders and validate these exploratory findings. Additionally, as a single-center study conducted in a specific regional population (Attica, Greece), the generalizability of these findings to other healthcare systems or industrial settings may be limited. Other potential confounders, including age-related inflammatory changes, co-morbidities, and non-occupational

environmental exposures, were not systematically adjustedfor due to the retrospective design.

Conclusion

Occupational history is a critical but often missing piece of the diagnostic puzzle in respiratory medicine. Our study suggests that specific occupational groups—particularly those in agriculture and forestry— are associated with unique BAL cytological profiles characterized by high total cell counts and specific inflammatory markers. The current 80% underreporting rate highlights a significant clinical gap that may lead to the underdiagnosis of work-related lung diseases. We recommend that a structured, ISCO-08 based occupational history become a mandatory component of the referral process for all patients undergoing bronchoalveolar lavage.

Acknowledgements

The authors would like to express their sincere gratitude to Konstantina Tsakanika (MD, Cytopathologist) and Michalis Patentalakis(MD, Pulmonologist) for their valuable contribution, support, and technical assistance during the data collection phase and the clinical evaluation of this study.

.

References

1. Blanc PD, Torén K. Occupational exposures and COPD. Eur Respir Rev. 2016;25(141):285-92. Available from:https://doi.org/10.1183/09031936.00118808
2. Cummings KJ, Lai PS, Redlich CA. Occupational and Environmental Contributions to Lung Disease. Clin Chest Med. 2020;41(4):xiii–xv.Available from:https://doi.org/10.1016/j.ccm.2020.09.001
3. Global Burden of Disease Collaborative Network. Global, regional, and national comparative risk assessment of 84 behavioural, environmental and occupational, and metabolic risks or clusters of risks, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017. Lancet. 2018;392(10159):1923-94. Available from: https://doi.org/10.1016/s0140-6736(18)32225-6
4. Meyer KC. Bronchoalveolar lavage as a diagnostic tool. Semin Respir Crit Care Med. 2007;28(5):546-60. Available from: https://doi.org/10.1055/s-2007-991527
5. Costa e Silva M, Rolo R. The role of Bronchoalveolar lavage in Interstitial Lung Diseases. Rev Port Pneumol. 2017;23(6):360–2.Available from:https://doi.org/10.1016/j.rppnen.2017.10.003
6. Quynh CTT, Van TN, Viet DNH, Thuy HTT, Van TP. Prevalence and associated factors of musculoskeletal disorders among aquaculture workers in Vietnam: A cross-sectional study.International Journal of Occupational Safety and Health. 2025;15(3):222-9. Available from: https://doi.org/10.3126/ijosh.v15i3.81632
7. Patel J, Ghosh T. Prevalence of musculoskeletal disorders among female workers in the fish processing industry in Odisha, India. International Journal of Occupational Safety and Health. 2025;15(3):239-49. Available from: https://doi.org/10.3126/ijosh.v15i3.79256
8. Cordeiro CR, Jones JC, Alfaro T, Ferreira AJ. Bronchoalveolar Lavage in Occupational Lung Diseases. Semin Respir Crit Care Med. 2007;28(5):504–13. Available from:https://doi.org/10.1055/s-2007-991523
9. Hnizdo E, Vallyathan V. Chronic Obstructive Pulmonary Disease Due to

Occupational Exposure to Silica Dust: A Review of Epidemiological and Pathological Evidence. Occup Environ Med. 2003;60(4):237–43. Available from:https://doi.org/10.1136/oem.60.4.237

10. Linaker C, Smedley J. Respiratory illness in agricultural workers. Occup Med (Lond). 2002;52(8):451–9. Available from:https://doi.org/10.1093/occmed/52.8.451

11. Ware LB, Matthay MA. The Acute Respiratory Distress Syndrome. N Engl J Med. 2000;342(18):1334–49.Available from:https://doi.org/10.1056/NEJM200005043421806

12. Domagała-Kulawik J, Skirecki T, Maskey-Warzechowska M, Grubek-Jaworska H, Chazan R. Bronchoalveolar lavage total cell count in interstitial lung diseases--does it matter? Inflammation. 2012;35(3):803–9.Available from:https://doi.org/10.1007/s10753-011-9378-5

International Journal of Occupational Safety and Health

ISSN: 2091-0878 (Online) ISSN: 2738-9707 (Print)

Original Article

Burnout syndrome and (self-) dehumanization among nurses in Intensive Care Units [ICUs]: A cross-sectional study

Pialoglou KK[1], Farantos G[1], Koupidis S[2], Thanasias E[1], Zagorianakou N[3], Dounias G[1]

[1] Department of Public Health Policy, University of West Attica (UNIWA), 196 Alexandras Avenue, 115 21 Athens, Greece.
[2] Occupational Physician, 196 Alexandras Avenue, 115 21 Athens, Greece.
[3] Nursing Department, University of Ioannina, Epirus, Greece.

ABSTRACT

Introduction: Burnout and dehumanization are frequent psychological phenomena in healthcare environments, particularly among nurses. While dehumanization may serve as an adaptive mechanism to manage emotional strain and enhance clinical efficiency, excessive or prolonged exposure can lead to self-dehumanization and disrupt nurse–patient relationships, ultimately impairing the quality of care. Therefore, the primary objective of this study was to investigate the prevalence of burnout syndrome and (self-)dehumanization among ICU nurses and to examine the correlation between these phenomena.

Methods: A cross-sectional study was conducted among 78 volunteer nurses employed in intensive care units [ICUs] of Evangelismos General Hospital in Athens, Greece. Data were collected using three validated questionnaires based on the Oldenburg Burnout Inventory and the Dehumanization and Mechanistic Self-Dehumanization scales developed by Katerina Roupa. Statistical analyses included Mann–Whitney, Kruskal–Wallis, and Spearman's rho tests, with the significance level set at 0.05.

Results: Most participants were female (67.9%) and over 40 years old (55.2%). Low burnout levels were found in 76.9% of participants, moderate in 15.4%, and high in 7.7%. Higher burnout levels were observed among nurses with lower educational backgrounds, permanent contracts, one or two children, and fewer working hours. Male nurses demonstrated higher dehumanization and self-dehumanization scores than females. Work exhaustion was associated with males having 3–10 years of experience. A significant negative correlation was found between self-dehumanization and burnout. Additionally, nurses who tended to dehumanize their patients were more likely to self-dehumanize.

Conclusion: Although dehumanization and self-dehumanization may function as emotional regulation strategies against burnout, they have detrimental implications for nursing care and therapeutic relationships. Preventive interventions should aim to balance emotional resilience with patient-centered care.

Keywords: Burnout, Dehumanization, Nurses, Occupational Stress, Self-Dehumanization

Corresponding author:

Konstantinos Kleon Pialoglou, MD, MSc
Department of Public Health Policy, University of West Attica (UNIWA), Athens, Greece
196 Alexandras Avenue, 115 21 Athens, Greece
E-mail: konspial@gmail.com
Tel.: +306980563716
ORCID ID: https://orcid.org/0009-0004-3122-8208

Date of submission: 12.12.2025
Date of acceptance: 10.03.2026
Date of publication: 15.04.2026

Conflicts of interest: None
Supporting agencies: The Institute for Research and Community Service, Universitas Jember, Indonesia
DOI: https://doi.org/10.3126/ijosh.v16i1.87241

Copyright: This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License

Introduction

Occupational burnout currently stands as one of the most critical psychosocial hazards threatening the stability of modern healthcare systems globally. This multifaceted syndrome is clinically delineated by a triad of symptoms: profound emotional exhaustion, the development of cynical or detached attitudes known as depersonalization, and a significantly diminished sense of personal professional accomplishment.[1] The intensive care unit (ICU) environment presents a uniquely demanding landscape; nursing professionals in this sector are incessantly subjected to extreme physical fatigue, severe emotional distress, and complex bioethical dilemmas, all of which substantially exacerbate the susceptibility to burnout syndrome.[2]

In the specific context of the Greek healthcare infrastructure, these systemic pressures are markedly intensified. The lingering repercussions of prolonged economic austerity have precipitated chronic staffing deficits and unfavorable patient-to-nurse ratios, thereby compounding the daily operational burden on medical staff.[3] Furthermore, the advent of the COVID-19 pandemic dramatically escalated this psychosocial load, triggering not only widespread burnout but also fostering subtle defense mechanisms such as emotional blunting and dehumanization. Consequently, the present study aims to rigorously examine the complex interrelationships between burnout, (self-)dehumanization, and empathy fatigue among nurses at "Evangelismos" General Hospital, Greece's largest tertiary institution.

The initial theoretical framework for burnout was established by Freudenberger in 1974,[4] describing it as a condition of severe physical and psychological fatigue stemming from prolonged occupational stress. Subsequently, Maslach and Jackson[1] (1981) systematized the syndrome through the Maslach Burnout Inventory (MBI), identifying three core components: emotional exhaustion, characterized by the draining of emotional reserves; depersonalization, involving a cynical or distant attitude towards care recipients; and reduced personal accomplishment, manifested as a sense of professional failure or incompetence. Recognizing its roots in the work environment, the World Health Organization has officially designated burnout as an "occupational phenomenon" within the ICD-11 framework.[5] In the nursing profession, the syndrome is frequently precipitated by systemic pressures such as rotating schedules, ethical conflicts, inadequate management, and constant confrontation with patient pain.[6,7] High Dependency Units (HDUs) represent exceptionally demanding settings where staff must handle intricate clinical cases, often with insufficient downtime for recovery or psychological backing.[8]

Continuous subjection to such intense environments may result in emotional numbing and the gradual decay of professional compassion, ultimately fostering dehumanization directed at both others and one's own self. Traditionally, has been interpreted as a protective strategy—a psychological shield allowing healthcare workers to detach from the anguish they witness.[9] Nevertheless, the theoretical perspective introduced by Haslam (2006) redefines this detachment as a fundamental denial of human attributes to oneself or other people.[10] This phenomenon manifests in two forms: animalistic, which negates features like civility and culture, or mechanistic, where one perceives themselves as an unfeeling automaton. Within the context of nursing, persistent depersonalization can progress into self-dehumanization, a state in which nurses adopt a self-perception of being merely functional tools for care delivery rather than independent human beings.[11] This transformation severely compromises empathy, heightens feelings of estrangement, and can sustain a destructive loop of occupational burnout.[12] Contemporary studies associate self-dehumanization with reduced psychological resilience and moral trauma, highlighting its complex negative consequences for both the

clinician mental health and the safety of patients.[13]

Empathy fatigue, often characterized as the accumulating emotional weight of caregiving, manifests when continuous contact with the trauma of others exhausts a professional's ability to empathize.[14] Within the nursing context, this phenomenon engages in a dynamic interplay with burnout, serving as a critical mediator that links emotional depletion to the development of depersonalization.[15] Research has steadily highlighted gender-specific variations: female nurses tend to show elevated levels of emotional exhaustion driven by societal role pressures and emotional work, while their male counterparts are more prone to higher rates of depersonalization and self-dehumanization, indicative of distinct gender-based adaptive strategies.[16] Furthermore, empathy fatigue can act as an antecedent to self-dehumanization, a state where the professional starts to undergo emotional numbing as a defensive psychological shield. These observations highlight the critical need for burnout prevention strategies that are tailored to address gender-specific needs.

The COVID-19 health crisis significantly amplified the mental strain placed on medical professionals. Specifically, nurses working in intensive care and high-dependency settings were forced to confront a continuous cycle of mortality, the danger of viral transmission, and profound social seclusion.[17] Within the Greek healthcare framework, the pandemic unveiled deep-seated structural flaws, including severe personnel deficits, the absence of mental health resources, and extended periods of emergency duty.[18,19] This intense environment did more than merely heighten emotional fatigue; it also hastened the development of dehumanization. Nursing staff frequently described experiences of feeling unseen, treated as objects, and sensing an internal erosion of their own human nature.[20] As a result, research emerging after the pandemic indicates a lasting shift in professional identity among nurses, marked by reduced empathetic capacity and a growing tendency to view oneself as a machine. The relationship between burnout, dehumanization, and empathy fatigue can be visualized as an evolving psychosocial spectrum. Long-term workplace stress leads to emotional depletion, which in turn activates dehumanization. When this detachment persists, it progresses into self-dehumanization, ultimately compromising both empathy and job satisfaction.

This approach synthesizes established psychosocial theories of burnout with growing scholarship on dehumanization, highlighting the cyclical pattern of emotional detachment and the critical requirement for systemic institutional support.

Understanding the dynamic relationship between burnout and (self-)dehumanization provides a theoretical basis for interventions aimed at rebuilding empathy and professional purpose. Specifically for nurses within Greek ICUs, this perspective emphasizes the necessity for structural reforms, peer-assistance networks, and resilience-oriented training initiatives. By anchoring this investigation at Evangelismos General Hospital—an environment characterized by extreme pressure and high acuity—the study enriches the global dialogue regarding healthcare worker welfare and stresses the ethical obligation to safeguard the psychological integrity of nursing staff.[21]

Methods

The aim of this cross-sectional study was to investigate the prevalence of professional burnout and its association with the demographic characteristics of the sample. Additionally, the study examined the levels of dehumanization and self-dehumanization among nurses and explored the relationship between these constructs and burnout in ICUs of the General Hospital "Evangelismos".

The study targeted the entire nursing staff of ICUs at the General Hospital "Evangelismos." No formal power analysis was conducted a priori; instead, a total population sampling strategy was

employed, targeting all eligible nurses in the specific high-acuity units. The ICUs included the Cardiac Infarction Unit (n=25), the Cardiothoracic Post-Anesthesia Care Unit (n=24), ICU-4 (n=37), and ICU-3 (n=20). A total of 78 completed questionnaires were collected from 106 eligible staff members.

Participants were included if they were nurses or nurse assistants, employed for at least six months in the respective unit, and fluent in Greek as their native language. This minimum tenure was established to ensure that participants had sufficient exposure to the chronic stressors of the ICU environment, thereby allowing for the potential development of burnout symptoms, rather than reflecting the acute adjustment stress typically experienced by new hires during their orientation phase. Staff members from other allied health professions (e.g., occupational therapists, speech therapists) were excluded. Additionally, six participants were excluded due to incomplete questionnaire responses or employment duration of less than six months.

The study employed a structured questionnaire to assess burnout, dehumanization, and self-dehumanization among nurses in the ICUs of the General Hospital "Evangelismos." The questionnaire consisted of 39 items rated on a 7-point Likert scale (1 = strongly disagree to 7 = strongly agree) and was divided into three sections:

- Section A: Dehumanization of patients
- Section B: Self-dehumanization of nurses
- Section C: Levels of professional burnout

The instruments used were based on the Oldenburg Burnout Inventory and the Dehumanization and Mechanistic Self-Dehumanization scales, with permission for use obtained from the respective authors. These tools were selected due to their relevance to the study context and prior validation in related research conducted by the University of Crete. Specifically, the original validation study demonstrated robust psychometric properties, including high internal consistency and construct validity, establishing the scales as reliable instruments for assessing dehumanization in healthcare settings.

The study adhered to ethical principles and research integrity guidelines. All participants were fully informed about the study purpose and procedures. Anonymity was guaranteed, and data collection was strictly for research purposes. Participation was voluntary, and withdrawal was allowed at any stage without consequence.

Data were analyzed using R software (version 4.1.1). Non-parametric statistical methods were applied because psychological scale scores did not follow a normal distribution:

- Mann–Whitney U test for comparisons of two independent groups (e.g., male vs. female).
- Kruskal–Wallis H test for comparisons of more than two independent groups (e.g., age groups, shifts).
- Spearman's rank correlation coefficient (ϱ) to assess associations between quantitative variables (e.g., years of experience, working hours).

A significance level of $\alpha = 0.05$ was used for all analyses.

Before analysis, questionnaire responses were aggregated into total scores for each subscale:

Burnout Questionnaire (Oldenburg Burnout Inventory)

Exhaustion: Sum of items C2, 4, 5, 8, 10, 12, 14, 16; higher scores indicate higher physical and emotional exhaustion.

Disengagement: Sum of items C1, 3, 6, 7, 9, 11, 13, 15; higher scores indicate greater disengagement and dissatisfaction with work.

- Burnout Severity: Low: ≤43, Moderate: 44–51, High: ≥52

Dehumanization Questionnaire

- Animalistic Dehumanization: Sum of items A1–A6

- Mechanistic Dehumanization: Sum of items A7–A12

Higher scores indicate greater dehumanization, as no standardized cut-offs exist.

Self-Dehumanization Questionnaire

- Scores were calculated from Section B items. Higher scores indicate greater levels of self-dehumanization, without standardized cut-offs.

In the present study, the internal consistency of the employed scales was satisfactory, with Cronbach's alpha coefficients of α = 0.85 for the Oldenburg Burnout Inventory, α = 0.82 for the Dehumanization Scale, and α = 0.89 for the Self-Dehumanization Scale.

Results

The sample consisted of 78 nurses, predominantly female, with an age range mostly between 25 and 45 years. The majority had between 5 and 15 years of professional experience, with educational levels varying from undergraduate degrees to higher qualifications. These demographic characteristics provide context for interpreting burnout and dehumanization scores, indicating that the participants represent a relatively experienced and professionally diverse nursing population. The sample comprised 78 nurses, predominantly female (67.9%), with professional profiles detailed in Table 1. The sample consisted of 78 nurses, predominantly female, with a professional profile.

Table 1. Demographic and occupational characteristics

Characteristic	Category	N	%
Gender	Male	25	32.1%
	Female	53	67.9%
	Other	0	0.0%
Age (years)	≤ 29	13	16.7%
	30–39	22	28.2%
	40–49	24	30.8%
	≥ 50	19	24.4%
Education	Secondary	4	5.1%
	Technical/Vocational	11	14.1%
	University	18	23.1%
	Postgraduate	45	57.7%
Work experience (years)	1–2	6	7.7%
	3–5	22	28.2%
	6–10	10	12.8%
	11–20	19	24.4%
	>20	21	26.9%
Employment contract	Permanent	56	71.8%
	Fixed-term	22	28.2%
Work shifts (per month)	Morning only	13	16.7%
	1–4 shifts	28	35.9%
	5–8 shifts	22	28.2%
	>8 shifts	15	19.2%
Marital status	Single	50	64.1%
	Divorced	9	11.5%
	Married	19	24.4%
Children	0	53	67.9%
	1	9	11.5%
	2	16	20.5%
Household members	0	26	33.3%
	1	23	29.5%
	2	11	14.1%
	3	16	20.5%
	4	2	2.6%

Descriptive statistics for the burnout subscales revealed that nurses reported high levels of emotional exhaustion (mean ± SD), suggesting significant psychological and physical fatigue

Dehumanization scores were moderate, indicating that while some distancing from work tasks was present, it was not extreme. Detailed

responses regarding the dehumanization of patients, reflecting moderate depersonalization levels, are presented in Table 2.

The detailed distribution of responses for the professional burnout items is illustrated in Table 3.

The statistical significance of these associations between burnout and demographic or occupational characteristics is detailed in Table 4.

Table 2: Results of Questionnaire A Responses (Dehumanization)

Question	Score 1 (N)	Score 1 (%)	Score 2 (N)	Score 2 (%)	Score 3 (N)
They are superficial individuals and lack depth	23	29.5%	19	24.4%	6
They are open-minded individuals who can think clearly	2	2.6%	2	2.6%	17	0.97	<0.001* (0.75-1.17)
They are cold individuals who behave as if they were robots/machines	9	11.5%	15	19.2%	15	1.67	<0.001* (1.38-1.94)
They are individuals who feel warmth in their relationships with others	0	0.0%	7	9.0%	18	0.84	<0.001* (0.63-1.26)
They behave as if they themselves were objects rather than human beings	22	28.2%	15	19.2%	17	0.90	<0.001* (0.74-1.05)
They are emotional individuals who show responsiveness and warmth	0	0.0%	6	7.7%	24	0.68	0.403 (-0.09-0.23)
They are rational and sensible individuals. They are intelligent	2	2.6%	3	3.8%	15	0.46	<0.001* (0.66-0.27)
They are inferior to the human species, like animals	52	66.7%	18	23.1%	2	**5.20**	**<0.001* (4.72-5.67)**

* At the significance level of 0.05

Table 3: Results of Questionnaire C Responses (Burnout)

Question	Score 1 (N)	Score 1 (%)	Score 2 (N)
I understand my patients	15	19.2%	27
I manage to achieve my goals with my patients	54	69.2%	18
I am confident that I can build a positive relationship with my patients	28	35.9%	26
I feel energetic at work	48	61.5%	24
I can understand how my patients feel about various things	22	28.2%	29
I can calmly handle problems that arise at work	13	16.7%	32

Table 4: Correlation between Total Burnout Score and Various Demographic and Occupational Characteristics

Variable	Test Used	Statistic	p-value
Gender	Mann-Whitney U Test	W = 671.5	0.927
Age	Kruskal-Wallis Test	$\chi^2 = 2.94$	0.402
Education	Kruskal-Wallis Test	$\chi^2 = 8.53$	0.0363
Years of Service	Kruskal-Wallis Test	$\chi^2 = 7.81$	0.099
Contract Type	Kruskal-Wallis Test	$\chi^2 = 5.27$	0.0217
Shifts	Kruskal-Wallis Test	$\chi^2 = 6.62$	0.0852

Overall, the results indicate a significant interplay between burnout, patient dehumanization, and self-dehumanization. Emotional exhaustion appears to be the most affected dimension of burnout, strongly linked to both forms of dehumanization. Depersonalization shows moderate associations, reflecting psychological distancing strategies. Both patient dehumanization and self-dehumanization may function as coping mechanisms under high work-related stress, yet they are simultaneously associated with higher burnout, highlighting a potentially maladaptive pattern among nursing staff.

Further analysis of the data revealed significant correlations between the variables under study. Specifically, Figure 1 reveals a significant negative correlation between self-dehumanization and burnout scores ($R = -0.54$, $p < 0.001$), suggesting that nurses who adopt a mechanistic view of themselves may report lower levels of exhaustion. This linear regression clearly shows the significant negative correlation between Self-Dehumanization and Total Burnout scores.

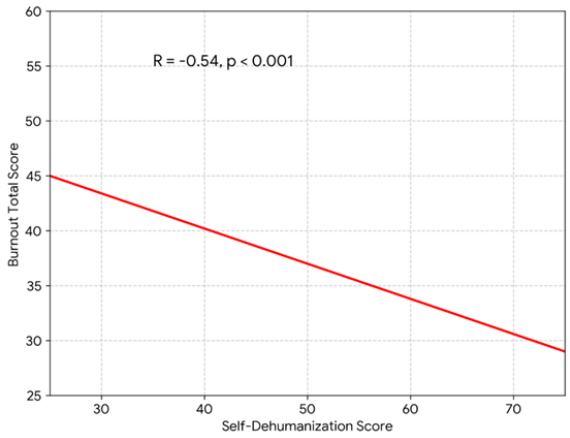


Figure 1. Linear regression showing the significant negative correlation between Self-Dehumanization and Total Burnout scores

Conversely, Figure 2 illustrates the correlation between patient dehumanization and burnout. This figure depicts the relationship between the Total Scores of the Dehumanization Questionnaire and Professional Burnout among the participating nursing staff.

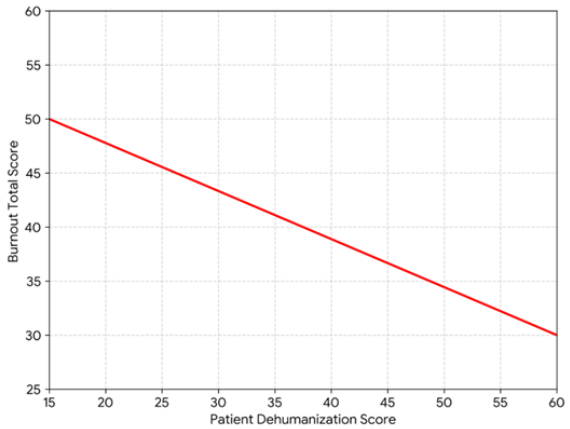


Figure 2. Correlation between Total Scores of the Dehumanization Questionnaire and Professional Burnout

Finally, as presented in Figure 3, correlation analysis revealed a significant positive association between patient dehumanization scores and self-dehumanization scores. This finding indicates that the tendency to objectify patients is closely linked to the process of objectifying oneself within the clinical setting.

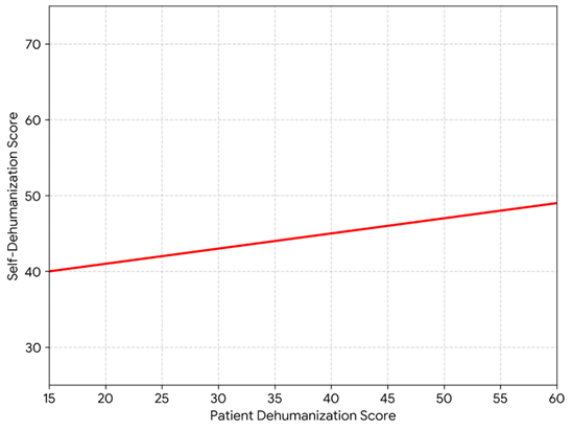


Figure 3. Association between Patient Dehumanization Score and Self-Dehumanization Score.

Discussion

The majority of the study cohort (76.9%) demonstrated low burnout scores. Conversely, elevated burnout levels, affecting 7.7% of the sample, were predominantly observed among participants with lower educational attainment, permanent employment status, parenthood (specifically one or two children), and a schedule with fewer working hours.

With respect to the correlation between academic background and occupational burnout, these results align with findings from a study involving 250 nurses across three hospitals in Shandong, China. That research confirmed that personnel holding a single degree experienced greater burnout, a trend attributed to performing less fulfilling duties than their more highly qualified colleagues. Furthermore, disparities were noted regarding secondary education, where university undergraduates exhibited the lowest burnout rates.[22]

In terms of working hours, evidence from two medium-sized medical facilities in Caceres, Spain, supports the observation that staff working 30-hour weeks reported intensified exhaustion compared to those on 40-hour schedules. However, this paradox warrants further investigation; a separate analysis of Finnish social and health systems suggests that nurses with reduced hours often seek supplementary employment to ensure economic viability and family welfare, resulting in total work overload and eventual occupational burnout.[23] This observation is particularly relevant in contexts of economic instability, where job precariousness compels professionals to view reduced hours not as an opportunity for rest, but as a financial deficit. This specific socioeconomic landscape distinguishes the present findings from studies in Asian contexts, such as Indonesia. While both regions face high demands, the Greek experience is uniquely shaped by the psychological impact of prolonged austerity and the loss of previously established resource levels, rather than by the challenges of rapid health system expansion. Consequently, the correlation between fewer hours and higher burnout likely reflects anxiety about income insecurity and the hidden, cumulative fatigue from engaging in secondary employment to maintain family well-being.

Regarding the relationship between contract type and burnout severity, research involving 651 nursing staff across 79 psychiatric units found that those with permanent tenure were slightly more prone to burnout and more inclined to leave the profession.[24] Conversely, conflicting evidence exists; for instance, a study focusing on registered nurses in three rural Spanish regions found that temporary staff—often characterized by younger age, less experience, or lower educational qualifications—

demonstrated elevated levels of occupational burnout, depersonalization, and personal accomplishment, likely exacerbated by employment instability.[25] Furthermore, an investigation involving 676 public hospital nurses in Spain revealed that parenthood was linked to higher reported levels of personal fulfillment and professional achievement compared to childless peers.[26]

The findings of the current research highlight a distinct gender disparity in dehumanization tendencies, with male nurses exhibiting significantly higher scores in both animalistic and mechanistic forms. A similar pattern emerged for self-dehumanization, with men again scoring higher than women. Additionally, an advanced educational background appears to be linked to increased mechanistic dehumanization, whereas mid-career experience (6–10 years) appears to offer a protective effect compared with those with 11–20 years of service. A strong positive correlation was also identified between working hours and mechanistic dehumanization, suggesting that as working hours increase, so does the tendency to dehumanize.

These observations align with a 2022 survey of 1,150 Greek healthcare workers, which found higher self-dehumanization among males than females, although hetero-dehumanization levels did not differ significantly by gender. That study also corroborated our finding that prolonged working hours and rotating shift patterns (as opposed to fixed shifts) are positively associated with mechanistic dehumanization.[27] This gendered disparity likely reflects deeply ingrained societal expectations regarding masculinity, particularly the ideal of stoicism, which discourages the overt expression of vulnerability. Consequently, male nurses may be more prone to adopting a mechanistic self-perception as a socially sanctioned coping mechanism, suppressing emotional distress to conform to traditional norms of resilience and professional detachment.

Concerning gender-specific manifestations of occupational burnout, existing literature indicates that female professionals predominantly experience emotional exhaustion, whereas their male counterparts are more likely to manifest distress through dehumanization.[28]

Regarding work-related exhaustion, prevalence was highest among males with 3 to 10 years of tenure. Conversely, rates were minimal for those with fewer than 3 years of experience and plateaued among those with more than a decade of service, likely attributable to accumulated experience. Analyzing shift patterns revealed that morning rotations were most strongly associated with exhaustion, whereas the category of eight shifts was associated with the lowest scores. Furthermore, disengagement was found to be statistically associated with holding permanent employment contracts and working fewer hours.

It is well-established that heavy workloads escalate stress and erode professional satisfaction within nursing, subsequently driving emotional exhaustion—a symptom particularly prevalent among married female nurses as a primary manifestation of burnout. While women are often viewed as the archetypal caregivers, they frequently encounter workplace discrimination and diminished professional confidence. In contrast, men often occupy positions of authority yet face intense pressure and ambitious expectations, which predisposes them to a distinct form of burnout characterized by dehumanization.[29]

A separate investigation undertaken across three private medical centers in Los Angeles revealed that 87 nurses, representing 24% of the cohort, had reached the stage of burnout, with a mean professional tenure of 9.86 years (SD = 6.59). The data indicated a sharp rise in burnout prevalence, from a mere 4% among those with less than 6 months of experience to a peak of 60% among veterans with 25 to 30 years of service. It appears that prolonged career engagement may precipitate a conflict between personal identity and professional role. Accumulating

dissatisfaction and difficult working environments often breed apathy; simultaneously, as the healthcare landscape evolves and turnover occurs, remaining senior staff are gradually superseded by younger recruits driven to maximize their performance.[30] The current study demonstrates a clear correlation: the more nurses tend to objectify their patients, the higher their susceptibility to self-dehumanization. Frequently, this process functions as a defensive shield, enabling caregivers to evade the psychological trauma and emotional toll inherent in alleviating human suffering. Consequently, clinicians may utilize the dehumanization of others as a strategic tool for emotional regulation to forestall exhaustion.

Conversely, becoming conscious of this behavior—a phenomenon known as meta-dehumanization—can trigger severe psychological repercussions, including shame, anger, sorrow, and ethical dissonance. This internal conflict destabilizes self-esteem and self-perception, eventually culminating in self-dehumanization. Indeed, evidence indicates that self-dehumanization is linked to social withdrawal and self-destructive behaviors.[31] Ultimately, perceiving employees as objects within the healthcare system may be associated with a higher tendency for professionals to adopt self-dehumanization strategies, as they struggle to maintain efficiency amidst intense pressure.

The present analysis identified a statistically significant inverse relationship between self-dehumanization and occupational burnout. This negative correlation is supported by independent research conducted on a cohort of 96 nurses in Krakow, Poland; that study established that nursing staff who adopted dehumanizing attitudes towards patients were more successful in managing occupational stress and burnout syndrome compared to colleagues who did not employ such behavioral strategies.[32] Beyond the statistical correlations, these findings reveal a profound human struggle within the ICU environment. The transition from burnout to self-dehumanization should not be viewed merely as a clinical symptom, but rather as a desperate unconscious survival strategy—a 'regulatory shield' adopted by nurses to withstand the relentless emotional trauma and accumulated 'emotional residue' of their daily practice. Consequently, this research provides an innovative viewpoint that extends beyond conventional burnout paradigms, identifying self-dehumanization as a critical, distinct dimension of occupational distress. While perceiving oneself as a mechanistic instrument of care may offer temporary respite from overwhelming psychological pain, it comes at a steep moral cost, gradually eroding the empathy that defines the nursing profession. This emotional severance effectively dismantles the therapeutic relationship; by shielding themselves from pain, nurses inadvertently withdraw the compassion required for healing, reducing the patient to a biological object and violating the ethical core of care. Consequently, effectively supporting the nursing community requires interventions that go beyond operational staffing; it demands creating psychological safety nets that allow nurses to process trauma without forfeiting their humanity.

Nonetheless, these defensive behaviors elicit detrimental reactions from care recipients, often resulting in treatment non-compliance, clinical relapse, and the induction of self-dehumanization within the patients themselves. Ultimately, while dehumanization and self-dehumanization may seemingly offer a functional method for regulating emotions, anxiety, and burnout, a wealth of evidence connects these processes to self-destructive behaviors, profound risks to mental well-being, and significant degradation in the quality of nursing practice and the integrity of the therapeutic relationship. To mitigate these maladaptive responses, institutions such as 'Evangelismos' General Hospital must prioritize the implementation of targeted preventive interventions. Specifically, establishing structured peer-support systems, such as Schwartz Rounds, can provide a psychologically

safe space for staff to process the 'emotional residue' of their work without judgment. Furthermore, integrating resilience training programs that focus on mindfulness and cognitive reframing is essential to equip nurses with healthier coping strategies than dehumanization. Ultimately, these clinical interventions must be supported by organizational commitment to adequate staffing and optimized shift rotations, ensuring that the emotional safety of the workforce serves as the foundation for sustainable, patient-centered care.

From an Occupational Health and Safety (OHS) perspective, mitigating self-dehumanization requires systemic administrative action rather than solely individual resilience. Specifically, hospital administrations should implement ergonomic rotation schedules that limit prolonged exposure to high-intensity trauma. Furthermore, targeted psychological counseling programs that emphasize empathy reconstruction should be integrated into standard occupational health protocols to ensure a safer, more sustainable work environment.

Limitation

The present study has certain limitations that must be acknowledged. First, the sample size (N=78), although representative of the specific high-acuity units examined within "Evangelismos" General Hospital, is relatively small and derived from a single tertiary institution. Furthermore, given the absence of a power analysis, this research should be interpreted as an exploratory study. This may limit the generalizability of the findings to the broader nursing population in different healthcare settings or geographical regions. Second, the cross-sectional design allows for the identification of associations but precludes the establishment of causal relationships between burnout, dehumanization, and sociodemographic factors. Finally, the use of self-reported questionnaires may introduce response bias, as participants might underreport socially undesirable attitudes such as dehumanization. Future longitudinal studies with larger, multi-center samples are recommended to further validate these findings.

farming activities, ensuring that ergonomic concerns are addressed systematically.[19-21]

The profound psychological toll and the adoption of self-dehumanization as a "regulatory shield" observed in our study align with broader systemic challenges within the Greek healthcare framework. Recent literature corroborates that severe occupational burnout is highly prevalent among Greek healthcare professionals across both public and private sectors, largely driven by chronic understaffing, intense workloads, and insufficient resources.[33] Furthermore, the manifestation of such extreme coping mechanisms underscores a fundamental deficit in the organizational safety culture. As recently highlighted, a compromised workplace safety climate in Greek public hospitals significantly exacerbates the psychological distress of healthcare workers, forcing staff to rely on maladaptive emotional detachment strategies when institutional support is inherently lacking.[34]

Addressing this moral imperative requires transitioning from individual-level coping strategies to systemic organizational reform. To successfully dismantle the pressures that compel nurses to sacrifice their humanity, healthcare organizations must implement structured monitoring of psychosocial hazards. The integration of Key Performance Indicators (KPIs) tailored to hospital occupational health and safety has been shown to be an essential strategy for mitigating workplace stressors and evaluating the effectiveness of health interventions.[35] By systematically tracking burnout and emotional well-being as core KPIs, institutions can foster therapeutic environments that sustain professional resilience, ensuring that the psychological safety of the nursing workforce is prioritized alongside patient care.[36]

Conclusion

The complex dynamics between burnout and dehumanization revealed in this study point to a profound crisis in critical care nursing. While further investigation is needed to fully map the consequences of these behaviors on patient outcomes and professional relationships, the core message is clear. Our findings underscore a critical moral imperative for healthcare organizations: to dismantle the systemic pressures that compel nurses to sacrifice their humanity as a psychological defense, and to transition instead toward therapeutic environments that sustain both professional resilience and the capacity for compassionate care.

Acknowledgements

N/A.

References

1. Maslach C, Jackson SE. The measurement of experienced burnout. Journal of Occupational Behavior. 1981;2(2):99–113. Available from: https://doi.org/10.1002/job.4030020205
2. Schaufeli WB, Leiter MP, Maslach C. Burnout: 35 years of research and practice. Career Development International. 2009;14(3):204-20. Available from: https://doi.org/10.1108/13620430910966406
3. Karanikola MN, Papathanassoglou ED, Mpouzika M, Lemonidou C. Burnout syndrome indices in Greek intensive care nursing personnel. Dimensions of Critical Care Nursing. 2012;31(2):94-101. Available from: https://doi.org/10.1097/DCC.0b013e3182445fd2
4. Freudenberger HJ. Staff burnout. Journal of Social Issues. 1974;30(1):159–65. Available from: https://doi.org/10.1111/J.1540-4560.1974.TB00706.X
5. World Health Organization. Burn-out an "occupational phenomenon": International classification of diseases. Geneva: WHO; 2019. Available from: https://www.who.int/news/item/28-05-2019-burn-out-an-occupational-phenomenon-international-classification-of-diseases
6. Blanco-Donoso LM, Garrosa E, Moreno-Jiménez J, Gálvez-Herrer M, Moreno-Jiménez B. Occupational psychosocial risks of health professionals in the face of the crisis produced by the COVID-19: From the identification of these risks to immediate action. International Journal of Nursing Studies Advances. 2020;2:100003. Available from: https://doi.org/10.1016/j.ijnsa.2020.100003
7. Farantos G, Dounias G. Key performance indicators in occupational health and safety of hospitals: A scoping review with meta-analysis. G Ital Med Lav Ergon. 2024;4(1):12-26. Available from: https://doi.org/10.69088/2024/kypr3
8. Arrogante O, Aparicio-Zaldivar E. Burnout and health among critical care professionals: The mediating role of resilience. Intensive and Critical Care Nursing. 2017;42:110–5. Available from: https://doi.org/10.1016/j.iccn.2017.04.010
9. Maslach C, Leiter MP. Understanding the burnout experience: Recent research and its implications for psychiatry. World Psychiatry. 2016;15(2):103–11. Available from: https://doi.org/10.1002/wps.20311
10. Haslam N. Dehumanization: An integrative review. Personality and Social Psychology Review. 2006;10(3):252–64. Available from: https://doi.org/10.1207/s15327957pspr1003_4
11. Roupa A, Patelarou A, Giakoumidakis K, Fousiani K, Miliaraki M, Stratidaki E, et al. Measurement of Dehumanization, Self-Dehumanization, and Empathy as Mediating Factors Among Healthcare Professionals. Healthcare. 2025;13(1):75. Available from: https://doi.org/10.3390/healthcare13010075
12. Vaes J, Muratore M. Defensive dehumanization in the medical practice: A cross-sectional study from a health care worker's perspective. British Journal of Social Psychology. 2013;52(1):180-90. Available from: https://doi.org/10.1111/bjso.12008

13. Hoogendoorn NJ, Rodríguez D. Rethinking dehumanization, empathy, and burnout in healthcare contexts. Current Opinion in Behavioral Sciences. 2023;52:101285. Available from: https://doi.org/10.1016/j.cobeha.2023.101285
14. Chen X, Chen M, Zheng H, Wang C, Chen H, Wu Q, et al. Effects of psychological intervention on empathy fatigue in nurses: A meta-analysis. Frontiers in Public Health. 2022;10:952932. Available from: https://doi.org/10.3389/fpubh.2022.952932
15. Salvagioni DAJ, Melanda FN, Mesas AE, González AD, Gabani FL, Andrade SM. Physical, psychological, and occupational consequences of job burnout: A systematic review. PLoS One 2017;12(10):e0185781. Available from: https://doi.org/10.1371/journal.pone.0185781
16. Purvanova RK, Muros JP. Gender differences in burnout: A meta-analysis. Journal of Vocational Behavior. 2010;77(2):168-85. Available from: https://doi.org/10.1016/j.jvb.2010.04.006
17. Wu J, Liang B, Chen C, Wang H, Fang Y, Shen S, et al. SARS-CoV-2 infection induces sustained humoral immune responses in convalescent patients following symptomatic COVID-19. Nat Commun. 2021;12(1):1813. Available from: https://doi.org/10.1038/s41467-021-22034-1
18. Pappa S, Ntella V, Giannakas T, Katsaounou P, Papoutsi E. Prevalence of depression, anxiety, and burnout among healthcare workers during the COVID-19 pandemic: A systematic review. Brain, Behavior, and Immunity. 2020;88:901-07. Available from: https://doi.org/10.1016/j.bbi.2020.05.026
19. Christofilea O, Farantos G, Psaridi L, Tsaousi M, Sartzi S, Dounias G. Assessment of Workplace Safety Climate among Healthcare Workers: A Case Study of the Public Sector Hospitals in Greece. ESI Preprints. 2025;21(37):146. Available from: https://doi.org/10.19044/esj.2025.v21n37p146
20. Køster A, Fernandez AV, Nielsen MS. Intensive care nurses' experiences of caring for isolated COVID-positive patients during first wave of COVID-19. Journal of the Intensive Care Society. 2023;24(4):379-85. Available from: https://doi.org/10.1177/17511437231160073
21. Farantos G, Christofilea O, Dounias G. Hospital occupational health and safety services and accidents in Greek hospitals: A case study in a Greek health region. Multidisciplinary Reviews. 2025;9(3):e2026119. Available from: https://doi.org/10.31893/multirev.2026119
22. Qu HY, Wang CM. Study on the relationships between nurses' job burnout and subjective well-being. Chinese Nursing Research. 2015;2(2–3):61-6. Available from: https://doi.org/10.1016/j.cnre.2015.09.003
23. França FM, Ferrari R, Ferrari DC, Alves ED. Burnout and labour aspects in the nursing team at two medium-sized hospitals. Revista Latino-Americana de Enfermagem. 2012;20(5):961-70. Available from: https://doi.org/10.1590/S0104-11692012000500019
24. Hult M, Halmine O, Mattila-Holappa P, Kangasniemi M. Health and work well-being associated with employment precariousness among permanent and temporary nurses: A cross-sectional survey. Nordic Journal of Nursing Research. 2022;42(3):140–6. Available from: https://doi.org/10.1177/20571585211070376
25. Oliveira B, Gehri M, Simon M. The deployment of temporary nurses and its association with permanently-employed nurses' outcomes in psychiatric hospitals: a secondary analysis. PeerJ. 2023;11:e15300. Available from: https://doi.org/10.7717/peerj.15300
26. Acea-Lopez L, Bravo-Pastor M, Arnaldo-Rubinat E, Bellon F, Blanco-Blanco J,Sanchez-Gea M et al. Burnout and job satisfaction among nurses in three Spanish regions. Journal of Nursing Management. 2021;29(7):2208–15. Available from: https://doi.org/10.1111/jonm.13376
27. Cañadas-De la Fuente GA, Vargas C, San Luis C, García I, Cañadas GR, De la Fuente EI. Risk factors and prevalence of burnout syndrome in the nursing profession. International Journal of Nursing Studies. 2015;52(1):240-9. Available from: http://dx.doi.org/10.1016/j.ijnurstu.2014.07.001
28. Roupa A, Patelarou A, Fradelos EC, Fousiani K, Miliaraki M, Giakoumidakis K, et al. Validation of

Two Instruments for the Measurement of Dehumanization and Self-Dehumanization in Healthcare Settings. Nursing Reports. 2024;14(3):2246-65. Available from: https://doi.org/10.3390/nursrep14030167

29. Olanrewaju S, Chineye O. Gender differences in burnout among health workers in the Ekiti State University Teaching Hospital Ado-Ekiti. International Journal of Social and Behavioural Sciences. 2013;1(6):112-21. Available from: https://www.researchgate.net/publication/272985631

30. Maghsoud F, Rezaei M, Asgarian FS, Rassouli M. Workload and quality of nursing care: the mediating role of implicit rationing of nursing care, job satisfaction and emotional exhaustion by using structural equations modeling approach. BMC Nursing. 2022;21:273. Available from: https://doi.org/10.1186/s12912-022-01055-1

31. McNeese-Smith DK. Job Stages of Entry, Mastery, and Disengagement Among Nurses. JONA: The Journal of Nursing Administration. 2000;30(3):140-7. Available from: https://doi.org/10.1097/00005110-200003000-00006

32. Hoogendoorn NJ, Rodríguez D. Rethinking dehumanization, empathy, and burnout in healthcare contexts. Current Opinion in Behavioral Sciences. 2023;52:101285. Available from: https://doi.org/10.1016/j.cobeha.2023.101285

33. Głębocka A. Stress and Dehumanizing Behaviors of Medical Staff Toward Patients. Adv Exp Med Biol. 2019;1133:97-104. Available from: https://doi.org/10.1007/5584_2018_308

34. Christofilea O, Farantos G, Psaridi L, Tsaousi M, Sartzi S, Dounias G. Assessment of Workplace Safety Climate among Healthcare Workers: A Case Study of the Public Sector Hospitals in Greece. European Scientific Journal. 2024;32:89. Available from: https://doi.org/10.19044/esj.2025.v21n37p146

35. Christofilea O, Farantos G, Psaridi L, Tsaousi M, Sartzi S, Dounias G. Assessment of Workplace Safety Climate among Healthcare Workers: A Case Study of the Public Sector Hospitals in Greece. Eur Sci J. 2025;21(37):146. Available from: https://doi.org/10.19044/esj.2025.v21n37p146

36. Farantos G, Dounias G. Key performance indicators in occupational health and safety of hospitals: A scoping review with meta-analysis. G Ital Med Lav. 2024;4(1):12-26. Available from: https://doi.org/10.69088/2024/KYPR3

International Journal of Occupational Safety and Health

ISSN: 2091-0878 (Online) ISSN: 2738-9707 (Print)

Original Article

Development of an attitude scale for occupational health and safety

Kazancı Yabanova E[1], Öztürk M[1]

[1] Department of Labour Economics and Industrial Relations, Isparta Süleyman Demirel University, Isparta, Türkiye.

Corresponding author:
Ecehan Kazancı Yabanova, PhD,
Department of Labour Economics and Industrial Relations,
Süleyman Demirel University,
Isparta, Türkiye.
E-mail: ecehankazanci@gmail.com
Tel.: +902462110401
ORCID ID: https://orcid.org/0000-0002-1602-2904

Date of submission: 29.08.2025
Date of acceptance: 06.04.2026
Date of publication: 15.04.2026

Conflicts of interest: None
Supporting agencies: None

DOI:https://doi.org/10.3126/ijosh.v16i1.83864

Copyright: This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License

ABSTRACT

Introduction: The concept of occupational health and safety has become one of the most fundamental issues in today's working life. This concept, which has extremely important implications in human, economic, legal and social dimensions, has created an important field of research in the scientific arena. The aim of this study is to develop an attitude scale towards occupational health and safety, which is one of the most current issues in working life.

Methods: In this study, scale design technique, one of the quantitative research methods, was used. The study was conducted on 554 blue-collar workers employed at two factories operating in the ceramics and forest products sectors in the Çanakkale Çan Organised Industrial Zone.

Results: A draft scale consisting of 50 items was developed. Exploratory factor analysis was performed with data collected from 277 participants, and the scale completed the EFA analysis with 34 items and 4 sub-factors.

Conclusion: As a result of the study, the Attitude Scale Towards Occupational Health and Safety was developed, consisting of four sub-factors (personal, management, education, and work environment) and 32 items.

Keywords: Attitude, Occupational health and safety, Scale

Introduction

A qualified and active workforce has become one of the most fundamental socio-economic indicators for societies today. In a competitive global environment, the workforce is one of the most important concepts to protect in working life for both economic and moral reasons. The production-oriented working conditions that emerged during the industrial revolution, in which the health and safety of workers were neglected, have now been transformed into a system that prioritizes worker health and safety. Of course, this transformation has not been easy; it has taken many years, and a series of framework regulations established by numerous international organizations, which have been enshrined in national legislation, to achieve the current structure. Despite its thousands of years of history, occupational health and safety still faces many

challenges that need to be overcome,[1] and has begun to be addressed more strongly at the national and international levels in terms of implementation and impact in the last quarter of a century.[2] Awareness of the negative effects of occupational accidents and diseases on workers and workplaces has increased, leading to the implementation of more preventive measures.[3]

Worker safety is extremely important for many reasons. While this concept is largely driven by business economic factors, it also takes on a moral dimension from the perspectives of workers, their families, and society, regarding the ability to lead a life befitting human dignity. Workplace accidents and occupational diseases result in significant losses for national economies, in addition to their human costs.[4] For employers, the economic factors of an employee's absence from work due to an accident or occupational disease, such as loss of manpower, difficulties in replacing qualified personnel, and compensation payments, come to the fore. On the other hand, the employee's permanent disability, inability to work due to an occupational disease, or loss of life due to an accident can result in irreparable consequences for their family and social life. In this sense, occupational health and safety is not only related to the economic dimension of production activities but also closely related to family happiness.[5] Another approach considers the protection of employees against work accidents and occupational diseases as related to the most basic human right, the right to life.[1]

To prevent these negative consequences, the concept of occupational health and safety has emerged as an extremely important issue in recent years. The primary goal of these practices is to prevent work accidents and occupational diseases before they occur, thereby protecting workers.[2,6] These approaches, which have gained momentum at the national and international levels, have led to the health and safety of workers becoming the most important aspect of working life. This issue, which is addressed in various laws regulating working life in Turkey, has been codified in the law, the Occupational Health and Safety Law No. 6331. This Law comprehensively addresses the requirements related to occupational health and safety in Turkish working life. With the entry into force of this Law in 2012, many duties and responsibilities have been imposed on employers and employees.

Statistics published since the Law took effect show that the desired reductions in workplace accidents and occupational diseases have not been achieved. This raises the question of why significant improvements have not been achieved despite these regulations, prompting scientific discussion. Most of the studies conducted have focused on the structural dimensions of occupational health and safety.[7] The approach adopted by employees, who are the subjects of the laws and regulations implemented, in the face of all these new circumstances, has gained importance. In this regard, the role of individual factors in occupational health and safety has come to the fore.[8,9] The attitude of workers towards this situation, which brings new tasks and responsibilities and creates changes in their usual work routines, has become a matter of interest. Attitude emerges as the most important dimension that drives behavior. Therefore, understanding employees' attitudes towards occupational health and safety provides an important starting point for understanding the behavior they will exhibit in this regard. Attitudes and professional culture are considered to be the most significant barriers to initiatives aimed at improving occupational health and safety.[10]. It is thought that the question of why employees do not exhibit behaviors consistent with occupational health and safety practices can be explained by the concept of attitude. Negative attitudes towards any phenomenon directly affect behavior. Therefore, understanding employees' attitudes towards occupational health and safety and taking additional measures to identify and eliminate negative attitudes can contribute to the desired behavior. Existing studies ignore attitudes towards occupational health and safety and therefore fail to provide solutions for its management.[5] Approaches that address the issue

primarily from technical, organizational, institutional, and legal perspectives tend to overlook individual factors related to these practices, which employees encounter in the workplace and which directly affect their own safety, or fail to address them holistically. Some scales developed in this field address employees' perceptions of safety culture,[11,12] behaviors related to safe working,13, and dimensions such as safety culture and teamwork.[14] The purpose of this study is to develop a scale to determine employees' attitudes toward occupational health and safety in terms of personal, management, education, and work environment dimensions.

Methods

This research is a scale development study. The research was conducted using a quantitative method and a survey design.[15] The aim was to develop a scale to evaluate blue-collar workers' attitudes towards occupational health and safety. In line with this aim, the 'Occupational Health and Safety Attitude Scale' was developed.

Study Group

The study group consisted of 554 participants working in two factories operating in the Ceramics and Forest Products sectors in the Çanakkale Çan Organized Industrial Zone. Çanakkale Çan Organized Industrial Zone was selected because it is an industrial zone with a high concentration of blue-collar workers and companies operating in high-risk sectors. Of the study group, 277 individuals formed the sample for the exploratory factor analysis process, and 277 individuals formed the sample for the confirmatory factor analysis process. Demographic information about the participants is presented in Table 1.

Table 1: Demographic Characteristics of the Study Group

		Exploratory Factor Analysis		Confirmatory Factor Analysis	
		n	%	n	%
Gender	Female	53	19.1	73	26.4
	Male	224	80.9	204	73.6
Marital Status	Married	205	74.0	212	76.5
	Single	72	25.9	65	23.5
Age	20 – 25 age	34	12.3	27	9.7
	26 – 30 age	54	19.5	26	9.4
	31 – 35 age	57	20.6	50	18.1
	36 – 40 age	59	21.3	51	18.4
	41 – 45 age	43	15.5	48	17.3
	46 and above	30	10.8	75	27.1
Educational Status	Primary school	56	20.2	73	26.4
	Middle school	48	17.3	50	18.1
	High school	105	37.9	120	43.4
	Vocational high school	37	13.3	19	6.9
	Bachelor's degree	23	8.3	15	5.4
	Master's degree	8	2.9	-	-

As shown in Table 1, the study groups in the EFA and CFA processes consist of an equal number of individuals with similar demographic characteristics.

Scale Development Stages

There are many stages in the scale development process, as indicated in the literature.[16] Within the scope of this study, the scale development process went through the stages indicated below prior to application.

- **Literature Review:** In the first stage of scale development, the literature review examined the field of occupational health and safety and attitudes. Scales developed for similar purposes in this field were examined, and a draft scale comprising 50 items was developed within the scope of the sub-factors of occupational health and safety and attitudes, and their relationship to each other. The statements were formulated in simple, easy-to-understand language.
- **Item Pool:** When creating the item pool, the theoretical information obtained from the literature review was carefully analyzed. Sub-factors were created by considering the three components of attitude: cognitive, behavioral, and affective. These three components were addressed separately within the personal, management, training, and work environment factors identified within the scope of occupational health and safety. Care was taken to develop statements related to attitude in the item pool that were both positive and negative and that included all three sub-factors of attitude.
- **Expert Opinion (Content Validity):** One of the methods used to test the content validity of a scale is content validity, which is determined by considering the opinions of experts in the field rather than determining the level of validity based on numerical values.[16] With the submission of the draft scale form to expert opinion, field experts evaluate the necessity, clarity, and originality of the questions. At this point, suggestions may be made to remove or modify some statements from the draft scale.[17] In this context, the statements in the item pool of the draft scale form prepared to determine content validity were submitted to expert opinion to ensure content and face validity. The draft scale form was submitted to five field experts: two in labor economics, two in scale development, and one in Turkish language. Necessary revisions were made to the items based on the opinions and suggestions of the field experts.
- **Pilot Application:** It is recommended that the number of people required for the pilot application in the scale development stage should not be less than 50.[18]

The draft scale, consisting of 50 items and evaluated by experts for content validity, was administered to 56 blue-collar workers randomly sampled from a factory operating in an organized industrial zone for a pilot application. The aim was to analyze any issues that may arise regarding readability, comprehensibility, etc., in a sample appropriate for the scale's target audience.

Limitations

This research was conducted as part of a scale development study, and the study group was limited to blue-collar workers employed at two factories in order to ensure a sufficient sample size for validity and reliability analyses. This may limit the generalizability of the findings to different sectors, job categories, or employee groups.

Results

The data collected from 554 participants for scale development were divided into two sets using a random split.[19] The first data set (N=277) was used in exploratory factor analysis, while the second data set (N=277) was used in confirmatory factor analysis. Descriptive analyses were conducted to assess the suitability of the draft scale dataset for EFA and CFA.

Table 2: Descriptive Analysis of Draft Scale Data

N	Average	Varians	Standard Deviation	Skewness	Kurtosis
554	206.53	332.054	18.22	-0.353	0.492

As a result of the analysis, it was observed that the skewness and kurtosis values of the data set were between -1.5 and 1.5, which are the reference values, and that the data set was suitable for the analyses.[20]

Exploratory Factor Analysis - EFA

EFA is used in the scale development process to relate a large number of items to a small number of factors or latent constructs.[21] During the analysis, it is recommended to perform rotation to clearly identify the factors and to facilitate the interpretation of highly correlated items.[20] In this context, the Varimax technique, which is an orthogonal rotation method, was applied to the Principal Component Analysis. As a result of the analysis, items 6, 9, 11, 15, 16, 20, 23, 38, 40, 42, 47, and 50, which had cross-loadings, and items 13, 39, 45, and 46, which had single-item-single-factor loadings, were removed from the scale. To determine whether the sample size and dataset were sufficient for factor analysis, the KMO and Bartlett's Test of Sphericity were applied.

Table 3: KMO and Bartlett's Test Analysis Results

Kaiser-Meyer-Olkin Measure of Sampling Adequacy		**.917**
Bartlett's Test of Globality	Approximate K-Square	6142.538
	df	561
	Significance (p)	0.000

The analysis revealed that the KMO value was 0.917 and Bartlett's Sphericity Test was significant (χ^2 [561] = 6142.538, $p < 0.001$). Accordingly, the sample size and data set are sufficient for factor analysis.[21] After removing the items obtained from the variance analysis, it was observed that the scale has a four-factor structure. This result is consistent with the number of sub-factors determined in the theoretical framework. The total variance analysis results are presented in Table 4.

Table 4: Total Variance Analysis Results

Factor	Total Factor Load	Varians (%)	Accumulated variance (%)
Factor 1	11.320	33.295	33.295
Factor 2	4.077	11.990	45.285
Factor 3	3.280	9.646	54.931
Factor 4	2.329	6.849	61.780

The analysis identified four factors with eigenvalues above 1, and the total variance explained by all factors was 61.78%. This value exceeds the 50% threshold accepted for scale studies in the social sciences.[22]

The analysis revealed four factors with eigenvalues above 1. The first factor accounts for 33.29% of the variance, the second for 11.99%, the third for 9.65%, and the fourth for 6.85%. The total variance of the four factors was 61.78%. This

value exceeds the 50% threshold accepted in the social sciences.[22] Another analysis used to determine the number of factors, the scree plot analysis, was also applied, and the four factors affecting bed breakage were identified on the graph. A transformed component distribution analysis was conducted on the 34 items and 4 factors identified through the extraction process.

Table 5: Distribution of Rotated Components of the OSH Attitude Scale

	Factor			
	1	**2**	**3**	**4**
Item 49	.785			
Item 32	.778			
Item 30	.776			
Item 41	.751			
Item 4	.751			
Item 21	.749			
Item 19	.748			
Item 43	.747			
Item 25	.747			
Item 36	.732			
Item 14	.725			
Item 27	.720			
Item 12	.706			
Item 1	.696			
Item 33		.822		
Item 35		.814		
Item 44		.775		
Item 29		.762		
Item 5		.695		
Item 31		.689		
Item 26		.686		
Item 28		.601		
Item 37			.774	
Item 18			.773	
Item 10			.756	
Item 2			.746	
Item 8			.739	
Item 48			.721	
Item 24			.694	
Item 3				.836
Item 7				.818
Item 22				.755
Item 34				.741
Item 17				.712

The analysis revealed that the factor loadings of all items exceeded the threshold values. Based on the four-factor theoretical model proposed during the scale development process, the factors were examined, and the sub-factors were named accordingly. Accordingly, the first factor was named Personal, the second Management, the third Education, and the fourth Work Environment.

The effect of scale items on the variance explained, which is an important indicator in the factor analysis stage, was also analyzed. A high value indicates that the item contributes significantly to the total variance, and it is

recommended that items with values above 0.40 be retained. The analysis revealed that all items exceeded the 0.40 threshold. Item discrimination analysis, an important indicator of structural validity, was also applied. The results of the upper-group–lower-group item-discrimination analysis for the scale formed after EFA are presented in Table 6.

Table 6: Scale Item Average Scores for the Lower Group (27%) and Upper Group (27%) Independent Sample T-Test Analysis

Item		$\bar{\chi} \pm Ss$	t	p	Item		$\bar{\chi} \pm Ss$	t	p
Item 1	Lower	4.00±0.70	11.579	0.000	Item 26	Lower	3.61±0.87	6.821	0.000
	Upper	5.00±0.00				Upper	4.56±0.73		
Item 2	Lower	4.00±0.70	10.902	0.000	Item 27	Lower	3.55±0.68	9.653	0.000
	Upper	4.97±0.17				Upper	4.59±0.55		
Item 3	Lower	4.35±0.67	7.317	0.000	Item 28	Lower	3.77±0.80	9.764	0.000
	Upper	4.97±0.17				Upper	4.85±0.40		
Item 4	Lower	3.83±0.69	12.936	0.000	Item 29	Lower	3.47±1.01	8.375	0.000
	Upper	4.97±0.17				Upper	4.65±0.54		
Item 5	Lower	3.58±0.84	8.451	0.000	Item 30	Lower	3.70±0.63	11.694	0.000
	Upper	4.62±0.55				Upper	4.80±0.44		
Item 7	Lower	4.33±0.71	6.338	0.000	Item 31	Lower	3.68±0.83	8.103	0.000
	Upper	4.92±0.27				Upper	4.73±0.65		
Item 8	Lower	4.05±0.71	8.642	0.000	Item 32	Lower	3.48±0.64	15.429	0.000
	Upper	4.88±0.33				Upper	4.86±0.35		
Item 10	Lower	3.92±0.71	10.733	0.000	Item 33	Lower	3.56±0.84	9.311	0.000
	Upper	4.92±0.27				Upper	4.73±0.57		
Item 12	Lower	3.86±0.58	11.418	0.000	Item 34	Lower	4.15±0.59	10.074	0.000
	Upper	4.83±0.38				Upper	4.94±0.24		
Item 14	Lower	3.50±0.68	11.415	0.000	Item 35	Lower	3.45±0.91	11.330	0.000
	Upper	4.73±0.54				Upper	4.83±0.38		
Item 17	Lower	4.06±0.68	9.095	0.000	Item 36	Lower	3.64±0.51	12.708	0.000
	Upper	4.89±0.31				Upper	4.76±0.50		
Item 18	Lower	4.00±0.66	10.288	0.000	Item 37	Lower	3.73±0.87	8.959	0.000
	Upper	4.92±0.32				Upper	4.79±0.41		
Item 19	Lower	3.86±0.65	10.689	0.000	Item 41	Lower	3.55±0.61	11.266	0.000
	Upper	4.86±0.39				Upper	4.65±0.51		
Item 21	Lower	3.64±0.57	15.296	0.000	Item 43	Lower	3.45±0.73	12.962	0.000
	Upper	4.88±0.33				Upper	4.79±0.41		
Item 22	Lower	4.21±0.54	9.979	0.000	Item 44	Lower	3.61±0.87	9.119	0.000
	Upper	4.94±0.24				Upper	4.73±0.48		
Item 24	Lower	3.61±0.76	11.948	0.000	Item 48	Lower	3.79±0.79	7.626	0.000
	Upper	4.86±0.39				Upper	4.70±0.55		
Item 25	Lower	3.70±0.58	13.345	0.000	Item 49	Lower	3.55±0.61	13.144	0.000
	Upper	4.83±0.38				Upper	4.76±0.43		

Table 7: Reliability Analysis of the OSH Attitude Scale after EFA

Factor	Cronbach Alpha
Personal	0.947
Management	0.894
Education	0.896
Work Environment	0.876
General	0.935

The analysis revealed significant differences between the upper and lower group scores for all items of the scale, indicating that all items are discriminative. Cronbach's alpha was calculated to assess the scale's internal consistency following EFA.

Accordingly, it was found that all factors were within the high-reliability range of .80 or above.[23] CFA analysis was performed to determine the scale's ability to produce consistent measurements after EFA.

Confirmatory Factor Analysis - CFA

The second part of the data set, which was randomly divided into two in the CFA process, was used. The analysis yielded CMIN/DF = 1.180, RMSEA = 0.026, CFI = 0.984, and GFI = 0.886. Since the GFI value was below the reference value of .90, improvements were made; however, sufficient improvement was not achieved, so a second improvement was made. Items 7 and 43 were removed from the model because they loaded on multiple factors. As a result, the CFA with 32 items showed that the model fit was achieved in all reference values.

Table 8: CFA Fit Index Values

Conformity Criteria	Good Conformity	Acceptable Conformity	Scale Value
p	$0.05 < p \leq 1.00$	$0.01 \leq p \leq 0.05$	0.128
χ^2 /df	$0 \leq X^2/df \leq 2$	$2 < X^2/df \leq 3$	1.076
RMSEA	$0 \leq RMSEA \leq 0.05$	$0.05 < RMSEA \leq 0.08$	0.017
NFI	$0.95 \leq NFI \leq 1.00$	$0.90 \leq NFI < 0.95$	0.915
CFI	$0.97 \leq CFI \leq 1.00$	$0.95 \leq CFI < 0.97$	0.993
GFI	$0.95 \leq GFI \leq 1.00$	$0.90 \leq GFI < 0.95$	0.903
AGFI	$0.90 \leq AGFI \leq 1.00$	$0.85 \leq AGFI < 0.90$	0.887

Source: (24)

Table 9: CFA Item Analysis

Factor	Item	β_0	β_1	S.E.	C.R.	p
Personal	1	0,797	1	-	-	
	4	0,753	0,912	0,065	13,982	*
	12	0,730	0,947	0,070	13,438	*
	14	0,815	1,037	0,067	15,565	*
	19	0,723	0,932	0,070	13,285	*
	21	0,802	1,049	0,069	15,214	*
	25	0,744	1,000	0,073	13,762	*
	27	0,798	1,005	0,067	15,111	*
	30	0,812	1,046	0,068	15,473	*
	32	0,811	0,979	0,063	15,442	*
	36	0,774	0,964	0,067	14,495	*
	41	0,793	0,911	0,061	14,997	*
	49	0,840	1,034	0,064	16,236	*
Management	5	0,657	1	-	-	
	26	0,779	1,149	0,102	11,220	*
	28	0,822	1,302	0,111	11,712	*
	29	0,771	1,119	0,101	11,126	*
	31	0,793	1,205	0,106	11,388	*
	33	0,556	0.840	0,101	8,348	*
	35	0,794	1,190	0,105	11,332	*
	44	0,747	1,053	0,098	10,785	*
Education	2	0,578	1	-	-	
	8	0,805	1,471	0,150	9,786	*
	10	0,757	1,374	0,146	9,432	*
	18	0,781	1,421	0,148	9,614	*
	24	0,730	1,407	0,152	9,224	*
	37	0,723	1,297	0,142	9,161	*
	48	0,701	1,213	0,135	8,985	*
Work Environment	3	0,786	1	-	-	
	17	0,694	0,990	0,088	11,294	*
	22	0,763	1,112	0,089	12,500	*
	34	0,793	1,079	0,083	12,958	*

β_0: Standardized loads β_1: Unstandardized loads S.E.: Approximate standard error C.R.: *t*-value P (*): 0.001 significance level

According to the analysis results, five of the seven indicator values in the confirmatory factor analysis process showed good fit, while two showed acceptable fit. CFA Item Analysis was performed to determine whether the items were loaded onto the factors at a meaningful level in accordance with the model.

The analysis showed that the scale met the model fit and structural validity criteria. As a result of CFA, the scale was finalized with 32 items and 4 factors. To determine internal consistency, Composite Reliability (CR) and Calculated Average Variance (AVE) values were examined

Table 10: Composite Reliability and Calculated Average Variance Analysis of Factors

Factor	CR	AVE
Personal	0.954	0.616
Management	0.908	0.554
Education	0.887	0.530
Work Environment	0.845	0.578

As a result of the analysis, the Composite Reliability (CR) value was found to be above the reference value of .70, and the Calculated Average Variance (AVE) value was also found to be above the reference value of .50. Accordingly, it was observed that the scale meets the convergent validity criteria. Another indicator value, discriminant validity, was also analyzed using the Pearson Correlation method.

Table 11: Correlation Between the Factors of the Scale

Factor	Personal	Management	Education	Work Environment	General
Personal	1				
Management	0.254 0.01	1			
Education	0.420 0.01	0.245 0.01	1		
Work Environment	0.365 0.01	0.244 0.01	0.456 0.01	1	
General	0.860 0.01	0.591 0.01	0.686 0.01	0.596 0.01	1

p <.01

The analysis revealed that the correlation coefficients among all factors were below the reference value of .80. This result indicates that the scale meets the criterion for discriminant validity. The CFA model obtained after all these analyses is shown in Figure 1

In the model, it can be seen that covariances exist between items 20-21 and 21-22. Factor loadings of .50 or higher, which is a sufficient value for ensuring construct validity, were obtained for all items, and factor loadings above .70, which is the ideal value, were obtained for 28 items. The internal consistency Cronbach's Alpha coefficient of the scale was calculated after CFA and is presented in Table 12.

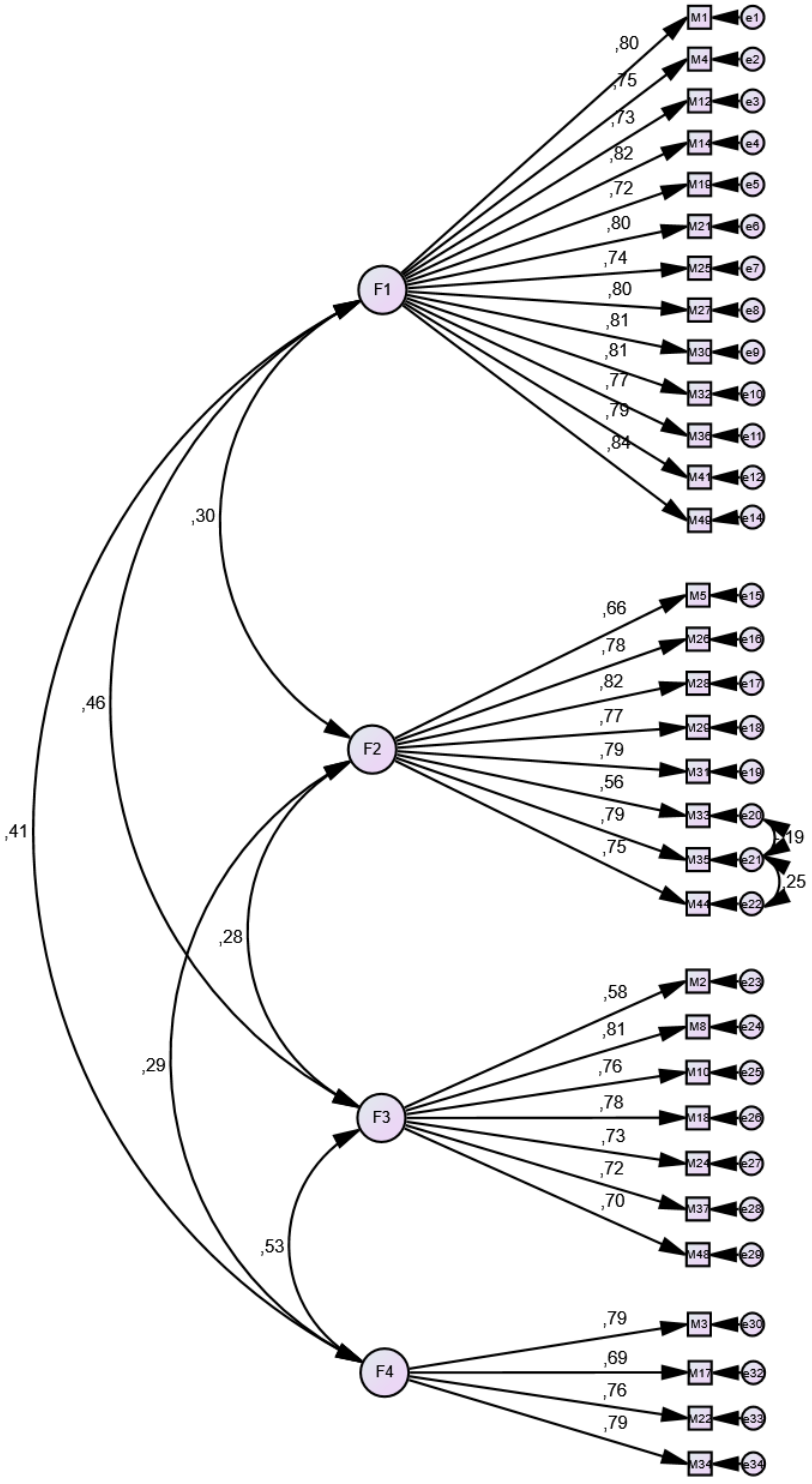


Figure 1: Standardized CFA Model of Scale Factors

Table 12: Reliability Analysis of the OSH Attitude Scale After CFA

Factor	Cronbach Alpha
Personal	.954
Management	.906
Education	.887
Work Environment	.842
General	.935

After all analyses, it was observed that the overall reliability of the scale was finalized with 32 items and 4 factors, and all sub-factors were at a high level.

Common Method Bias Control

Common method variance,[25] which is seen as a problem arising from the data collection method, was analyzed with single-factor control. According to this, the total variance of the first factor, to which EFA was applied without rotation, was determined as 25%. In another single-factor analysis, the entire data set was analyzed using Varimax rotation, and the first factor accounted for 18% of the total variance. Both values were found to be well below the threshold value of 50%,[26] and it was concluded that there was no common method bias in the research data.

Discussion and Conclusion

Attitude is considered one of the most important cognitive components that trigger behavior. Without direct behavioral support from employees, it is not possible to achieve the desired success in ensuring employee health and safety through occupational health and safety practices. Despite the implementation of numerous national regulations on occupational health and safety in recent years, there have been no significant reductions in occupational accidents, necessitating a deeper examination of the issue from employees' perspective.

In this context, the attitude scale developed in our study reveals employees' attitudes towards occupational health in four sub-factors. It is anticipated that determining employees' attitudes towards occupational health practices in the personal, managerial, educational, and work environment factors, identifying any low attitudes in these areas, and supporting occupational health and safety practices with a set of additional measures to improve these attitudes will lead to positive improvements in employee behavior. For example, if a group of employees has a very low attitude level in the managerial dimension, it is extremely important to develop additional training content to increase managerial attitudes in occupational health and safety training. Only then will a holistic attitude improvement and behavioral patterns be supported. It has been observed that positive developments occur when hospital employees are included in occupational health and safety decision-making processes.[24] At this point, it is seen that each sub-factor studied within the scope of the scale has a separate effect.

The occupational health and safety attitude scale development study began with 50 items and resulted in a final scale with 32 items and 4 factors. During the exploratory factor analysis, 16 questions were excluded from the scale because they fell outside the reference values, and the EFA was completed with 34 items. As a result of the CFA analyses, the scale was finalized with 32 items and 4 factors. This scale will help determine employees' attitudes towards occupational health and safety before implementing any occupational health and safety measures. It will provide an important starting point for businesses and researchers working in the field, from the content of the training to the identification of current employee perspectives. In addition to determining employees' readiness levels and providing standard occupational health and safety training, it is anticipated that adding content dimensions that address identified deficiencies will increase the effectiveness of the training provided. In particular, determining employees' current attitude levels in line with the organizational psychology approach, analyzing the employee by taking them into consideration in the activity to be carried out, and adopting an approach that values the employee will contribute to the formation of an organizational culture that values its employees, transforming occupational health and safety practices from mechanical activities into a human-centered approach.

Acknowledgement

This study is based on the first author's doctoral thesis, which was supervised by the second author. It was approved by the Ethics Committee of Süleyman Demirel University by decision no. 117/12.

References

1. Guo HR. Frontiers and challenges in occupational safety and health. Frontiers in Public Health. 2014;2(85):1-3. Available from: https://doi.org/10.3389/fpubh.2014.00085
2. Akkaya MA. Bilgi Merkezlerinde İş Sağlığı ve Güvenliğinin Önemi ve Uygulanabilirliğine İlişkin Bir Durum Değerlendirmesi. Türk Kütüphaneciliği. 2017;31(4):501-19. Available from: https://doi.org/10.24146/tkd.2017.23
3. Fernandez-Muniz B, Montes-Peon JM, Vazquez-Ordas CJ. Safety management system: Development and validation of a multidimensional scale. Journal of Loss Prevention in the Process Industries. 2007;20(1):52-68. Available from: https://www.sciencedirect.com/science/article/abs/pii/S0950423006000660
4. Alli BO. Fundamental principles of occupational health and safety. 2nd ed. Geneva: ILO. 2008. Available from: https://www.ilo.org/publications/fundamental-principles-occupational-health-and-safety-second-edition
5. Li S, Chen H, Huang X, Hou C, Chen F. Chinese Public Response to Occupational Safety and Health Problems—A Study Based on Psychological Distance. International Journal of Environmental Research and Public Health. 2019;16(11):1944. Available from: https://doi.org/10.3390/ijerph16111944
6. Soyal H, Sarihan M, Yarar O. Occupational Health Safety Effect on Hospital Safety. Acta Physica Polonica A. 2020;137(4):579-82. Available from: https://doi.org/10.12693/APhysPolA.137.579
7. Njeru DK. Factors that influence implementation of occupational safety and health management system at public universities in kenya—A case study of Egerton university. Int. J. Curr. Res. 2014;6(5):6602–9. Available from: https://www.journalcra.com/article/factors-influence-implementation-occupational-safety-and-health-management-system-public
8. Beus JM, McCord MA, Zohar D. Workplace safety: A review and research synthesis. Organizational Psychology Review. 2016;6(4):352–81. Available from: https://doi.org/10.1177/2041386615626243
9. Vierendeels G, Reniers G, van Nunen K, Ponnet K. An integrative conceptual framework for safety culture: The Egg Aggregated Model (TEAM) of safety culture. Safety Science. 2018;103:323–39. Available from: https://doi.org/10.1016/j.ssci.2017.12.021
10. Lindahl C, Bergman-Bruhn A, Andersson IM. Occupational safety climate in the Swedish equine sector. Animals. 2022;12(4):438. Available from: https://doi.org/10.3390/ani12040438
11. Zohar D. Safety climate in industrial organizations: Theoretical and applied implications. Journal of Applied Psychology. 1980;65(1):96–102. Available from: https://doi.org/10.1037/0021-9010.65.1.96
12. Hayes BE, Perander J, Smecko T, Trask J. Measuring perceptions of workplace safety: Development and validation of the Work Safety Scale. Journal of Safety Research. 1998;29(3):145–61. Available from: https://doi.org/10.1016/S0022-4375(98)00011-5
13. Neal A, Griffin MA. A study of the lagged relationships among safety climate, safety motivation, safety behavior, and accidents at the individual and group levels. Journal of Applied Psychology. 2006;91(4):946–53. Available from: https://doi.org/10.1037/0021-9010.91.4.946
14. Sexton JB, Helmreich RL, Neilands TB, Rowan K, Vella K, Boyden J, et. al. The Safety Attitudes Questionnaire: Psychometric properties, benchmarking data, and emerging research. BMC Health Services Research. 2006;6(44). Available from: https://doi.org/10.1186/1472-6963-6-44
15. Büyüköztürk Ş. Sosyal bilimler için veri analizi el kitabı (19th Eds.). Ankara: Pegem Akademi. 2014.

Available from: https://doi.org/10.14527/9789756802748

16. Tavşancıl E. Tutumların ölçülmesi ve SPSS ile veri analizi (6th Eds.). Ankara: Nobel Akademik Yayıncılık. 2019. Available from: https://www.nobelyayin.com/tutumlarin-olculmesi-ve-spss-ile-veri-analizi-2495.html
17. DeVellis RF. Scale Development Theory and Applications Second Edition (Chapter 5). SAGE Publications International Educational and Professional Publisher. 2003. Available from: https://books.google.com.tr/books?id=BYGxL6xLokUC
18. Karasar N. Bilimsel Araştırma Yöntemi. Ankara: Sanem Matbaası. 2024. Available from: https://www.nobelyayin.com/bilimsel-arastirma-yontemi-kavramlar-ilkeler-teknikler_1755.html
19. Stuart J, Scott R. The Measure of Online Disinhibition (MOD): Assessing Perceptions of Reductions in Restraint in the Online Environment. Computers in Human Behavior. 2021;114:1-11. Available from: https://doi.org/10.1016/J.CHB.2020.106534
20. Tabachnick BG, Fidell LS. Using Multivariate Statistics (6th Eds). Boston: Pearson Education. 2013. Available from: https://books.google.com.tr/books/about/Using_Multivariate_Statistics.html?hl=tr&id=ucj1ygAACAAJ
21. Worthington RL, Whittaker TA. Scale Development Research: A Content Analysis and Recommendations for Best Practices. The Counseling Psychologist. 2006;34(6):806–38. Available from: https://doi.org/10.1177/0011000006288127
22. Barrett KC, Leech NL, Morgan GA. IBM SPSS For Intermediate Statistics: Use and Interpretation (5th Eds). New York: Routledge, Taylor & Francis Group. 2014. Available from: https://doi.org/10.4324/9780203122778
23. Özdamar K. Paket Programlar ile İstatistiksel Veri Analizi Cilt 1. Ankara: Nisan Kitabevi. 2012. Available from: https://www.nisankitabevi.com/paket-programlar-ile-istatistiksel-veri-analizi-cilt-1
24. Schermelleh-Engel K, Moosbrugger H, Hans M. Evaluating the fit of structural equation models: Tests of significance and descriptive goodness-of-fit measures. Methods of Psychological Research Online. 2003;8(2):23-74. Available from: https://doi.org/10.23668/psycharchives.12784
25. Jordan PJ, Troth AC. Common Method Bias in Applied Settings: The Dilemma of Researching in Organizations. Australian Journal of Management. 2019;45(1):3–14. Available from: https://doi.org/10.1177/0312896219871976
26. Lings IN, Greenley GE. Measuring Internal Market Orientation. Journal of Service Research. 2005;7(3):290-305. Available from: https://doi.org/10.1177/1094670504271154

International Journal of
Occupational Safety and Health

ISSN: 2091-0878 (Online) ISSN: 2738-9707 (Print)

Original Article

Factors affecting risk level of work postures of durian farmers during pesticide spraying in southern peninsular Thailand: A cross-sectional study

Wittayasilp S[1], Senthong P[2]

[1]Department of Industrial and Manufacturing Engineering, Faculty of Engineering, Prince of Songkla University, Hat Yai, Songkhla 90112, Thailand.
[2]Faculty of Science and Industrial Technology, Prince of Songkla University, Surat Thani Campus, Muang, Surat Thani 84000, Thailand.

Corresponding author:
Pattama Senthong,
Lecturer, Faculty of Science and Industrial Technology, Prince of Songkla University, Surat Thani Campus, Surat Thani, Thailand.
E-mail: pattama.s@psu.ac.th
Tel.: +660659235156
ORCID ID: http://orcid.org/0000-0002-7497-3054

Date of submission: 15.01.2026
Date of acceptance: 01.04.2026
Date of publication: 15.04.2026
Conflicts of interest: None
Supporting agencies: Prince of Songkla University
DOI:https://doi.org/10.3126/ijosh.v16i1.89360

Copyright: This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License

ABSTRACT

Introduction: Work-related musculoskeletal disorders (WMSDs) are a major occupational health problem among farmers in Thailand. The purpose of this study was to evaluate the risk level and risk factors in work posture of durian farmers during pesticide spraying.

Methods: This cross-sectional study was carried out among 82 durian farmers (n = 82) in southern peninsular Thailand. A questionnaire was used to collect data on socio-demographics and work characteristics. The posture analysis during pesticide spraying was done using Rapid Entire Body Assessment (REBA). The Chi-squared test was applied to find associations between socio-demographics or work characteristics with the risk level according to REBA assessments, with statistical significance requiring $p<0.05$.

Results: REBA assessments indicated that most work postures during pesticide spraying by durian farmers had a high risk. Ergonomic risk factors for durian farmers involved prolonged work while standing in awkward postures, including bending the neck with more than 20° extension, bending the trunk with 0°-20° extension, raising and abducting the shoulder, both hands holding spray handles all the time, or carrying backpack pesticide sprayers with weights from 8 to 22 kg. Season, age, monthly income, pesticide spraying experience, pesticide spraying on other plants, pesticide spraying method, frequency of spraying pesticide, and durian tree height were statistically significantly associated with risk levels of work postures during pesticide spraying by durian farmers.

Conclusion: Therefore, regular ergonomic training accompanied by modifications to the workstations and to tools for pesticide spraying are essential in improving work postures during pesticide spraying by durian farmers.

Keywords: durian farmer, ergonomics, pesticide spraying, work posture

Introduction

Thailand is an agricultural country, where the majority of people are farmers. Thailand is the largest producer of durian and has the largest annual durian exports. The area of durian production has significantly increased from 838,714 rai in 2017 to 1,069,668 rai in 2020 (one rai equals 1,600 square meter area).[1] The durian production in the southern peninsular region has reached 47.4 percent of the total durian production in Thailand. In addition, most durian farmers are in this southern region (65.6 percent) and they produce durian both in its peak season

and out of season.[1] Based on the statistics provided by the Bureau of Occupational and Environmental Diseases (BOED), farmers are the category with the most prevalent musculoskeletal disorders. The number of farmers in Thailand who suffer from musculoskeletal disorders has increased steadily: 38,793 (2016), 62,806 (2017) and 70,184 (2018).[2] Many studies that relate to work posture and musculoskeletal disorders of farmers in Thailand have been published. A study of rice farmers during rice field preparation in Khon Kaen province found that experience and age were significantly associated with body pain and cramping. The most complaints of work-related musculoskeletal disorders (WMSDs) among more experienced farmers concerned their legs.[3] A study on Cambodian fruit farm workers in eastern Thailand indicated that the operations of mixing and of spraying pesticides, and of harvesting fruits, pose very high risks according to the Rapid Upper Limb Assessment (RULA) method. The body parts with the most discomfort to workers in a Cambodian fruit farm were lower back, neck, and shoulders. Risk factors for work related discomforts were age, length of work history, plantation area, and unhealthy work postures.[4] The organic farmers from Yasothorn province showed significantly more pain, numbness, or weakness in the wrists/hands, fingers, upper back, hips and ankles/feet than conventional farmers using pesticides from Nakorn Sawan and Phitsanulok provinces. Organic farmers do not use pesticides and take care of plants by sitting or squatting near the plants and removing weeds by hand.[5] The three top ranked risk factors to WMSDs of elderly farmers in Pathumthani province were bending trunk forward, bending the neck, and twisting the trunk. The Rapid Entire Body Assessment (REBA) indicated that most elderly farmers had a high risk level.[6] Lower back pain was the most prevalent musculoskeletal disorder in rubber farmers of southern Thailand, followed by hip/thigh and ankle/foot pains. RULA method reported that postures during tapping rubber trees and collecting rubber latex had a medium risk.[7]

WMSDs are a major occupational health problem for farmers worldwide. In Malaysia, REBA method revealed that most of the postures during harvesting and collecting fresh fruit bunches of oil palm were in the very high-risk level. The main types of activities inducing WMSDs were holding and swinging chisel and sickle, and these required further investigation and changing the action soon.[8] Another study from Malaysia showed that the most complaints of WMSDs among oil palm fresh fruit harvesters were from lower back pain, followed by knee, shoulder and neck regions. Musculoskeletal symptoms in the past 12 months were significantly associated with duration of employment, and daily work and rest durations.[9] Conventional method of maize seeding in Malaysia is related to an awkward posture with repetitive movements, sit squatting, bending the knee, and digging a hole. REBA and RULA methods indicate the conventional method as having a high risk, whereas lightweight motorized maize seeder had a low risk. Moreover, the lightweight motorized maize seeder was faster than the conventional method in seeding maize.[10] In Indonesia, the highest prevalences of disorders for rice farmers in Bantul province from manually planting rice in the rice field were in waist, right and left shoulder, and back. REBA method showed the manual method as having a high risk with a score of 10, but a rice planter tool gave a medium risk with a score of 4. Rice planter tool increased the productivity twofold and reduced the risk of WMSDs.[11] The 9 activities of rice farmers in West Java province are use of a hoe manually for land clearing, grass cutting, planting the rice, manual plowing, applying fertilizer, harvesting, threshing, cleaning the rice from the straw, and sun-drying of rice. REBA method reported that the four activities manual plowing, manual use of hoe for land clearing, grass cutting, and threshing, were of a high risk. Most rice farmers suffered from musculoskeletal disorders in shoulder and lower back. Risk factors for work related discomforts were lifting and carrying heavy loads, repeated whole body bending, and highly repetitive handwork.[12] Another study on rice farmers in Central Java showed that neck and

lower back pain were the most prevalent musculoskeletal disorders. REBA method indicated that most rice farmers had a medium risk with a score of 7, and RULA method showed a high risk with a score of 7. The three top-ranked risk factors associated with WMSDs were heavy loads, bending the back, and sitting position.[13] The most suffered WMSD symptom of elderly farmers was lower back pain, and these musculoskeletal disorders were significantly associated with work position. The main types of activities inducing lower back pain were prolonged standing, body bending and body rotation approximately 4 times per minute.[14] In Iran, the main types of activities in manual sesame seed harvest were mowing, tying, and shaking. Ovako work posture analysis system (OWAS) indicated that stooped and squatting postures and heavy lifting were the dominant risk factors associated with lower back pain.[15] The 5 tasks of a pistachio farmer were picking pistachios from trees, carrying cloth wrappers for loading, shoveling pistachios into a hulling machine, washing pistachios, and transferring bags to a warehouse; and these were identified as high risk. Shoulder pain was the most prevalent musculoskeletal disorder, followed by lower back and wrist/hand pains. Musculoskeletal disorders were associated with repetitive motions, excessive force, awkward postures, and prolonged sitting and standing.[16] In Colombia, the 4 activities of natural rubber tappers were latex tapping, latex collection, mixing in two-roll mills, and metallic mold operations. The major risk factors were awkward posture, repetitive movements, and manual handling of heavy loads, which caused back and leg disorders.[17] In Spain, the normal work in melon cultivation involves transplanting, manual spraying, tractor spraying, leaf removal, harvesting, and cleaning. OWAS indicated that melon cultivation was dominantly of medium risk (47.57%), followed in rank by high risk (14.32%) and very high risk (0.47%). Mostly the posture has bent back, holding both arms below shoulder level, standing on two straight legs, and with a work load of less than 10 kg.[18]

Many studies have been performed on work posture, risk factors, and musculoskeletal disorders associated with rice, fruit, rubber, and organic farming, and associated with elderly farmers in Thailand. Additionally, there are many studies relevant to WMSDs among oil palm, maize, rice, sesame, pistachio, rubber, and melon farmers, and on elderly farmers worldwide. Limited studies have included durian farmers. Therefore, this study focused on factors affecting risk level of work postures of durian farmers during pesticide spraying in southern peninsular Thailand.

Methods

A cross-sectional study was conducted in durian farmers of southern peninsular Thailand, from November 2019 to September 2021. Durian farmers in this region prefer to grow durian because of its high sales price, while the price of rubber is relatively depressed. As a result, the agricultural area to grow durian has expanded in some areas. The areas for rubber trees, or fruits such as rambutan, have transitioned to growing durian instead. Durian is grown both in-season and out of season. In-season for durian is from July to August, while its off-season is from December to March. In this study, the top 2 areas in the southern region with the highest durian yield (kg) per rai were selected, namely Nakhon Si Thammarat and Surat Thani provinces. To sample in Nakhon Si Thammarat province, Tha Sala district was selected because it has the most durian cultivation and is a high yielding area. Moreover, most of the durian farmers are mainly producing durian out of season. In Surat Thani province, Na San district was chosen because of the highest durian yield per rai, and most of the durian farmers producing durian in-season. The sample size was determined using the Krejcie and Morgan table with an acceptable margin of error of 5% and a confidence level of 95%. According to the Krejcie and Morgan table, from a population of 101 individuals, a minimum sample size of 80 participants was required. Lists of registered durian farmers in the selected districts were obtained from local agricultural offices. Eligible

farmers were assigned identification numbers and selected using simple random sampling with a computer-generated random number list, resulting in a total of 82 participants being recruited for the study. All those randomly selected durian farmers aged from 20 to 60 years who had been spraying pesticide for one year or more and were still spraying pesticide in durian farm when they were invited to participate, were included in the study. An informed consent was obtained from each of the durian farmers, and the study was approved by the Health Science Human Research Ethics Committee, Prince of Songkla University (HSc-HREC-60-005-10-1).

The questionnaires collected data on demographics and work characteristics, including gender, weight, height, age, marital status, highest education level, monthly income, pesticide spraying experience (years), spraying pesticide on other plants, pesticide spraying method, frequency of spraying pesticide (days/year), duration of pesticide spraying (h), and durian tree height. All questions were multiple-choice type or open ended.

Work postures of individual durian farmers during pesticide spraying were captured by using a video camera and cropped to produce snapshots. Video recordings were reviewed frame-by-frame. The most frequent posture was defined as the posture maintained for the longest cumulative duration during pesticide spraying. The worst posture was defined as the posture exhibiting the greatest degree of joint deviation from neutral position and highest biomechanical load, based on Rapid Entire Body Assessment (REBA) scoring criteria (Table 1). REBA was designed by MacAtamney and Hignett, and this method is divided into 2 sections, of which section A includes neck, trunk, and legs, and section B covers upper arms, lower arms and wrists. This method also evaluates force and load, coupling, and muscle activity. Scores are calculated for the posture during each task, and these are classified into five risk levels: very low risk (score 1), low risk and change may be needed (score 2-3), medium risk, further investigation and change soon (score 4-7), high risk, investigate and implement change (score 8-10), and very high risk and implement change (score $\geqslant$ 11).[19] REBA scoring was conducted independently by two trained assessors with experience in ergonomic evaluation. The inter-rater reliability was assessed using Cohen's kappa coefficient, with a value of 0.89 indicating substantial agreement between the raters.

Descriptive analysis was used to determine the frequencies and percentages of risk levels from REBA assessments. The Chi-squared test was applied to find associations between socio-demographics or work characteristics with risk level according to REBA assessments, with statistical significance requiring $p<0.05$. In addition to Chi-square tests, effect size was calculated using Cramer's V to assess the magnitude of associations between categorical variables and risk level of work postures. The magnitude of association was interpreted according to conventional benchmarks, where values of approximately 0.10, 0.30, and 0.50 indicate small, moderate, and large effect sizes, respectively. Effect size measures were reported to complement p-values and provide information on the strength of associations. Because multiple associations were examined, the likelihood of type I error due to multiple comparisons may have increased. No formal adjustment for multiple testing was applied; therefore, the findings should be interpreted cautiously.

Results

In this study involving 82 durian farmers, there were mainly males (73.2%) with a male to female ratio of 3:1. The participants ranged in age from 20 to 59 years with average age of 38.0±12.4 years. Most of them were married (91.5%).

Table 1. REBA methods.

Part of body/ Activity	REBA method
Neck	score 1: 0°-20° flexion
	score 2: > 20° flexion or > 20° extension
	+1 score: twisting and side bending
Trunk	score 1: upright
	score 2: 0°-20° flexion or 0°-20° extension
	score 3: 20°-60° flexion
	score 4: > 60° flexion
	+1 score: twisting and side bending
Legs	score 1: bilateral weight bearing
	score 2: unilateral weight bearing or an unstable posture
	+1 score: knee between 30°-60° flexion
	+2 score: knee > 60° flexion
Upper arms	score 1: 20° extension to 20° flexion
	score 2: > 20° extension/20°-45° flexion
	score 3: 45°-90° flexion
	score 4: > 90° flexion
	+1 score: arm is abducted or rotated/shoulder is raised
	-1 score: supporting weight of arm
Lower arms	score 1: 60°-100° flexion
	score 2: 0°-60° flexion or > 60° flexion
Wrists	score 1: 0°-15° flexion or 0°-15° extension
	score 2: >15° flexion or >15° extension
	+1 score: deviated or twisted
Force and Load	score 0: load <11 lbs
	score 1: load 11-22 lbs
	score 2: load >22 lbs
	+1 score: rapid built up of force
Coupling	score 0: fitting handle and mid rang power grip
	score 1: acceptable but not ideal hand hold or coupling
	score 2: hand hold not acceptable but possible
	score 3: no handles
Muscle Activity	score 1: static/dynamic

Score	Risk level
1	very low risk
2-3	low risk and change may be needed
4-7	medium risk, further investigation and change soon
8-10	high risk, investigate and implement change
≥ 11	very high risk and implement change

The participants' weight ranged mostly between 45 kg and 55 kg (39.0%). Most of them were in the 161-170 cm height range (41.5%). The mean weight and height of durian farmers were 61.0±10.1 kg and 163.5±9.0 cm. Monthly income was 5,000-10,000 Thai baht for the majority (59.8%), while 19.5% and 20.7% reported 10,000-15,000 and more than 15,000 Thai baht, respectively. Most of the durian farmers had received education up to high school or primary school level (83.0%). The majority of durian farmers reported spraying pesticide 2-4 hours per day (84.2%) and 20-40 days per year (90.2%). On an average pesticide spraying took 2.9±1.1 hours per day and 34.9±5.0 days per year. Most durian farmers reported having pesticide spraying experience of 1-5 years (56.1%) and no spraying of pesticide on other plants (65.9%). Stationary tank was used by 96.3% of durian farmers to spray pesticides, while 3.7% of them used backpacks. Most durian trees had more than 5 m height (78.1%) (Table 2).

Table 2. Socio-demographics and work characteristics of durian farmers (N = 82).

Characteristic	Durian farmers, n (%)
1. Gender	
Male	60 (73.2)
Female	22 (26.8)
2. Weight (kg)	
45-55	32 (39.0)
56-65	23 (28.0)
66-75	18 (22.0)
> 75	9 (11.0)
Average	61.0±10.1
3. Height (cm)	
141-150	8 (9.8)
151-160	24 (29.3)
161-170	34 (41.5)
> 170	16 (19.4)
Average	163.5±9.0
4. Age (year)	
21-30	27 (33.0)
31-40	23 (28.0)
41-50	16 (19.5)
51-60	16 (19.5)
Average	38.0±12.4
5. Marital status	
Single	7 (8.5)
Married	75 (91.5)
6. Highest education level	
No education	7 (8.5)
Primary school	40 (48.8)
High school	28 (34.2)
Diploma	7 (8.5)
7. Monthly income (Thai baht)	
5,000-10,000	49 (59.8)
10,000-15,000	16 (19.5)
> 15,000	17 (20.7)
8. Pesticide spraying experience (year)	
1-5	46 (56.1)
5-10	11 (13.4)
> 10	25 (30.5)
9. Spraying pesticides on other plants	
Yes	28 (34.1)
No	54 (65.9)
10. Pesticide spraying method	
Backpack	3 (3.7)
Stationary pesticide tank	79 (96.3)
11. Frequency of spraying pesticide (day/year)	
< 20	6 (7.4)
20-40	74 (90.2)
> 40	2 (2.4)
Average	34.9±5.0
12. Duration of pesticide spraying (h/day)	
< 2	5 (6.1)
2-4	69 (84.2)
5-6	7 (8.5)
> 6	1 (1.2)
Average	2.9±1.1
13. Durian tree height (m)	
<5	18 (21.9)
>5	64 (78.1)

A stationary tank or, alternatively, a backpack was used as pesticide sprayer equipment. Stationary tank sprayers are used to spray pesticides in a large durian farm or with durian trees with heights exceeding 5 m. Normally, a

durian farmer mixes pesticide and water in a 1,000 L stationary tank, which is placed on the ground (Figure 1A). Backpack pesticide sprayers are used to spray pesticides at small durian farms and for durian trees of height less than 5 m. The portable backpack pesticide sprayers have weights from 8 to 22 kg (Figure 1B). Posture risk for durian farmer during spraying pesticide was incurred by prolonged standing in awkward postures, including bending the neck with more than 20° extension, bending the trunk with 0°-20° extension, unilateral weight bearing and knee at 30°-60° flexion, raising and abducting the shoulder, upper arms in more than 90° flexion, lower arms in more than 100° flexion, wrist in 0°-15° flexion, or both hands holding sprayer handles all the time (Figure 1).

The REBA method indicated that no durian farmers during pesticide spraying were classified as having very low or low risk. Most work postures of durian farmers during pesticide spraying had a high risk (Table 3).

Table 3. Frequency distribution and percentage of risk according to REBA assessment in work posture of durian farmers (N = 82) during pesticide spraying.

Risk level	Frequency (%)
Very low	0 (0%)
Low	0 (0%)
Medium	13 (15.9%)
High	62 (75.6%)
Very high	7 (8.5%)

(A) **(B)**

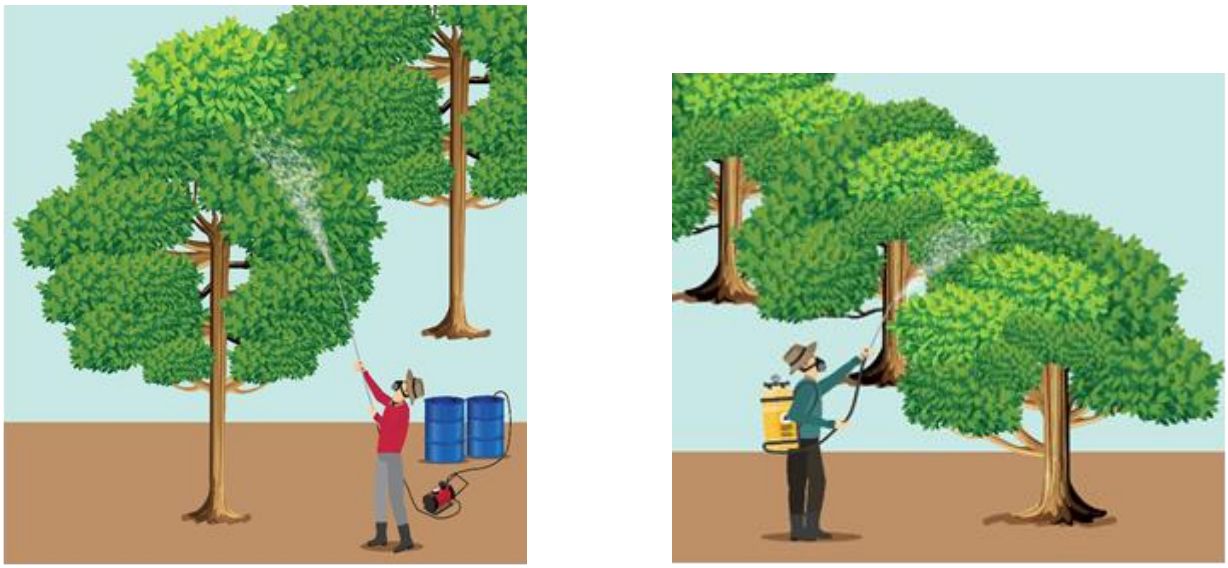


Figure 1. Work postures of durian farmers during pesticide spraying. Stationary pesticide tank (A), and backpack sprayer (B)

Durian farmers producing durian in-season are classified as having very high risk more often (17.7%) than those producing out of season (2.1%). Females were exposed to high and very high risk less than males. Weight range 66-75 kg is categorized more often as very high risk (16.7%) than the others, whereas 45-55 kg was indicated as high risk (87.5%) more often than the others. Rank order for body height by very high risk was: >170 cm (18.8%) > 151-160 cm (8.3%) > 161-170 cm (5.9%). Durian farmers in age range 41-50 years were not exposed to very high risk, whereas 51-60 years range had the most very high risk. Durian farmers that were single were not exposed to very high risk while most of these had high risk. Those with no education were classified as high (85.7%) and very high risk (14.3%) more often than others. In the very high risk category, monthly income > 15,000 Thai baht (17.6%) was 1.5 and 4-fold more often than 10,000-15,000 (12.5%) and 5,000-10,000 (4.1%) Thai baht incomes. Most durian farmers having

pesticide spraying experience for more than 10 years are classified as having very high risk (12.0%) but those with 5-10 years had no very high risk. Durian farmers spraying pesticide on other plants were classified as having very high risk (14.3%) more than those not spraying pesticide on other plants (5.5%). Durian farmers using backpack to spray pesticides (n = 3) were categorized as having high and very high risk more often than those using a stationary tank. This subgroup had small cell counts, Fisher's exact test was not applied, which may affect the stability of the estimates. However, this finding should be interpreted cautiously due to the small sample size. Only spraying pesticide 20-40 days per year was indicated as high (16.2%) and very high risk (1.4%). Durian farmers spraying pesticide 2-4 h/day (7.2%) were categorized as having very high risk less than those spraying for 5-6 h/day (28.6%). Durian trees of height more than 5 m incurred high and very high risk more often than trees of height less than 5 m. Chi-square analysis identified statistically significant associations between risk level and season ($p = 0.007$), age ($p = 0.017$), monthly income ($p = 0.000$), pesticide spraying experience ($p = 0.007$), spraying pesticide on other plants ($p = 0.019$), pesticide spraying method ($p = 0.000$), frequency of spraying pesticide ($p = 0.000$), and durian tree height ($p = 0.010$). Effect size analysis using Cramer's V indicated moderate associations for most significant factors ($V = 0.29–0.41$), while pesticide spraying method demonstrated a strong association with risk level ($V = 0.59$) (Table 4).

Discussion

Most work postures of durian farmers during pesticide spraying in this study had a high risk according to REBA method, whereas earlier reports indicated 'very high risk' to Cambodian and to vegetable greenhouse farmers in China, assessed by RULA method.[4,20] Numerous factors could have caused these differences, including assessment method, sample size, task distribution, length of work day, pesticide sprayer equipment used, and personal characteristics of the farmers such as height, age, and BMI. The RULA method weighs the scores for neck, lower arms, wrists, wrist twist, and force and load more than the REBA method. The RULA method is used in ergonomic investigations of workplaces with work related upper limb disorders, whereas the REBA method is used to investigate work postures of the upper limbs as well as the lower limbs along with coupling.

Posture risk for durian farmer during spraying pesticide was from prolonged standing, repetitive movements of shoulders, arms and wrists, and also from work with their hands above their shoulders. This is similar to the work posture of fresh fruit bunch cutters at oil palm plantations, usually working standing and holding a chisel or sickle overhead to cut the oil palm fruit for a prolonged period of time. Accordingly, work posture of fresh fruit bunch cutters indicates high risk and very high risk by both REBA and RULA assessments.[8,9,21,22,23,24] Furthermore, pesticide spraying was associated with neck and shoulder pain among female farmers in India,[25] and also male farmers in India reported very moderate to severe pain in neck, shoulder, upper arm, lower arm, and palm/fingers while spraying pesticide.[26]

The result of this study showed a significant correlation of risk level from work postures of durian farmers during spraying pesticide with season, age, monthly income, pesticide spraying experience, spraying pesticide on other plants, pesticide spraying method, frequency of spraying pesticide, and durian tree height.

Table 4. Factors associated with risk level of work postures of durian farmers (N = 82) during spraying pesticide.

Factor	Frequency (%)			Chi-square	P	Cramer's V
	Medium	High	Very high			
1. Season				9.971	0.007*	0.35
In season (n = 34)	8 (23.5)	20 (58.8)	6 (17.7)			
Out of season (n = 48)	5 (10.4)	42 (87.5)	1 (2.1)			
2. Gender				1.490	0.475	0.13
Female (n = 22)	5 (22.7)	16 (72.7)	1 (4.6)			
Male (n = 60)	8 (13.3)	46 (76.7)	6 (10.0)			
3. Weight (kg)				6.978	0.323	0.21
45-55 (n = 32)	4 (12.5)	28 (87.5)	0 (0)			
56-65 (n = 23)	3 (13.0)	17 (73.9)	3 (13.0)			
66-75 (n = 18)	4 (22.2)	11 (61.1)	3 (16.7)			
> 75 (n = 9)	2 (22.2)	6 (66.7)	1 (11.1)			
4. Height (cm)				3.423	0.754	0.14
141-150 (n = 8)	1 (12.5)	7 (87.5)	0 (0)			
151-160 (n = 24)	4 (16.7)	18 (75.0)	2 (8.3)			
161-170 (n = 34)	6 (17.6)	26 (76.5)	2 (5.9)			
> 170 (n = 16)	2 (12.5)	11 (68.7)	3 (18.8)			
5. Age (year)				15.460	0.017*	0.31
21-30 (n = 27)	1 (3.7)	24 (88.9)	2 (7.4)			
31-40 (n = 24)	2 (8.3)	20 (83.4)	2 (8.3)			
41-50 (n = 15)	4 (26.7)	11 (73.3)	0 (0)			
51-60 (n = 16)	6 (37.5)	7 (43.8)	3 (18.7)			
6. Marital status				0.769	0.681	0.10
Single (n = 7)	1 (14.3)	6 (85.7)	0 (0)			
Married (n = 75)	12 (16.0)	56 (74.7)	7 (9.3)			
7. Highest education level				3.793	0.705	0.15
No education (n = 7)	0 (0)	6 (85.7)	1 (14.3)			
Primary school (n = 40)	9 (22.5)	28 (70.0)	3 (7.5)			
High school (n = 28)	3 (10.7)	23 (82.1)	2 (7.2)			
Diploma (n = 7)	1 (14.3)	5 (71.4)	1 (14.3)			
8. Monthly income (thai baht)				24.258	0.000*	0.38
5,000-10,000 (n =49)	2 (4.1)	45 (91.8)	2 (4.1)			
10,000-15,000 (n =16)	8 (50.0)	6 (37.5)	2 (12.5)			
> 15,000 (n =17)	3 (17.6)	11 (64.8)	3 (17.6)			
9. Pesticide spraying experience (year)				14.133	0.007*	0.29
1-5 (n =46)	2 (4.4)	40 (86.9)	4 (8.7)			
5-10 (n =11)	5 (45.5)	6 (54.5)	0 (0)			
> 10 (n =25)	6 (24.0)	16 (64.0)	3 (12.0)			
10. Spraying pesticide other plants				7.902	0.019*	0.31
Yes (n =28)	8 (28.6)	16 (57.1)	4 (14.3)			
No (n =54)	5 (9.3)	46 (85.2)	3 (5.5)			
11. Pesticide spraying method				28.045	0.000*	0.59
Backpack (n =3)	1 (33.3)	1 (33.3)	1 (33.3)			
Stationary tank (n =79)	68 (86.0)	11 (14.0)	0 (0)			
12. Frequency of spraying pesticide (day/year)				26.992	0.000*	0.41
< 20 (n =6)	6 (100.0)	0 (0)	0 (0)			
20-40 (n =74)	61 (82.4)	12 (16.2)	1 (1.4)			
> 40 (n =2)	2 (100.0)	0 (0)	0 (0)			
13. Duration of pesticide spraying (h/day)				5.792	0.447	0.19
< 2 (n =5)	0 (0)	5 (100.0)	0 (0)			
2-4 (n =69)	12 (17.4)	52 (75.4)	5 (7.2)			
5-6 (n =7)	1 (14.3)	4 (57.1)	2 (28.6)			
> 6 (n =1)	0 (0)	1 (100.0)	0 (0)			
14. Durian tree height (m)				9.186	0.010*	0.34
< 5 (n =18)	7 (38.9)	10 (55.5)	1 (5.6)			
> 5 (n =64)	6 (9.4)	52 (81.2)	6 (9.4)			

* Significant at $p < 0.05$

Work postures of durian farmers during pesticide spraying when producing durian in-season are classified as very high risk more than when producing out of season. This may be a result of the size of the durian plantation, which is larger for in-season than for out of season, leading to a high workload, long hours, and fatigue. This correlates with prior results, suggesting that farmers with large harvests often work longer hours and experience fatigue, especially during peak harvest and production seasons.[27]

This study found that durian farmers who were 51-60 years old had the highest risk. This matches prior study results, indicating that elderly farmers in Thailand and Indonesia have inappropriate work postures, causing high risk.[6,14] It is also consistent with a study conducted in Bangladesh, which found that agricultural workers who were 41-60 years old normally suffered from musculoskeletal disorders.[28] Moreover, for farmers over 45 years of age, a high frequency of musculoskeletal disorders is associated with back, shoulder and leg pains.[29,30,31,32] In addition, aging is a risk factor for work-related musculoskeletal disorders among farmers due to decreased functional capacity, reduced physical strength and endurance, and a comparatively limited range of joint motion.[5,14,33,34,35,36,37]

Durian farmers who had a comparatively high monthly income > 15,000 Thai baht had very high risk more frequently than those who had 5,000-10,000 baht incomes. This agrees with earlier study results, which found that a high salary was associated with musculoskeletal pain for manually harvesting farmers in India.[31]

Durian farmers who had pesticide-spraying experience of more than 10 years had a higher risk than those who had been spraying for 5-10 years or 1-5 years. Likewise, durian farmers who were spraying pesticides 20-40 days per year had a higher and very high risk than when spraying < 20 days per year. These results match a prior study, which found that fruit farm workers in Thailand who had been spraying pesticide for longer than 10 years had a 1.66-fold risk of neck pain relative to those who had sprayed for < 1 year.[4] This is also similar to various studies, which indicated that a longer work history in agriculture increases the risk of musculoskeletal disorders. [20,21,25,28,31,34,38,39,40]

Durian farmers spraying pesticides on other plants are at a very high risk from work posture, more so than those not spraying pesticides on other plants. This result agrees with a study conducted on Cambodian fruit farm workers and another on rice farmers in Thailand, which reported that a larger plantation area related to the amount of work and increased fatigue, causing more musculoskeletal disorders.[4,41]

Durian farmers used portable backpack sprayers weighing 8-22 kg to spray pesticides, resulting in higher and very high risk more often than with a stationary tank. This is similar to previous studies in which farmers in Thailand, Korea and Brazil had musculoskeletal problems from carrying heavy spray tanks.[42,43,44] It also matches a study that reported that fruit farm workers who had been backpack-spraying pesticides had a high risk of neck and shoulder pain.[4]

The height of a durian tree is correlated with its age. Durian farmers are exposed to ergonomic work conditions that depend on the height of their durian trees. The results from this study indicate that a durian tree with a height exceeding 5 m has 1.5 times the risk of a shorter tree (height < 5 m). When the durian tree grows taller, durian farmers, during pesticide spraying, usually work while standing and need to bend their necks and trunks upward while their arms are raised above shoulder height, with repeated movements and forceful gripping of spray handles for a prolonged time. Awkward postures of neck and trunk cause constant pressure on spine and neck muscles, and also stress and strain ligaments, increasing intervertebral disc pressure; potentially causing pains in upper back, lower back, neck and shoulders.[45] Awkward postures of wrists and

thumbs, repeated movements, and forceful gripping can cause inflammation and swelling in wrists and thumbs, which is called tendonitis.[46] The results of this study are in agreement with the results of other studies that have indicated risks from awkward postures during harvesting oil palm due to the height of oil palm trees (> 3 m).[20,21]

This study has several limitations. First, due to its cross-sectional design, the findings reflect associations rather than causal relationships. Second, data on work characteristics were collected using self-reported questionnaires, which may be subject to recall bias. Third, although posture assessment was conducted using a standardized REBA method, observer bias cannot be entirely excluded. In addition, some subgroup analyses involved small sample sizes, and Fisher's exact test was not performed. Furthermore, the relatively small sample size and recruitment from only two provinces in southern peninsular Thailand may limit the generalizability of the findings to other agricultural settings or durian farmers in different regions. Therefore, the results should be interpreted with caution, and longitudinal studies with larger and more diverse populations are warranted to confirm these findings.

The strength of this study lies in the ergonomic risk assessment using the REBA method among all 82 durian farmers. The findings show that most postures during pesticide spraying pose a high risk and may lead to awkward postures for farmers. The study recommends medical surveillance for musculoskeletal disorders in high-risk groups, particularly farmers aged over 50 years, with more than 10 years of spraying experience, frequent spraying (20–40 days/year), use of backpack sprayers, and working with durian trees taller than 5 m. Durian farmers often perform repetitive movements while firmly gripping spraying equipment, which may lead to tendonitis in the wrists and thumbs. Using support wraps, braces, and gentle stretching before and during spraying can help reduce musculoskeletal symptoms. When spraying trees taller than 5 m, prolonged standing and upward bending of the neck and trunk, with arms raised, increase the risk of pain in the back, neck, and shoulders. Backpack sprayers are typically used for trees under 5 m in height. Durian farmers carried backpack pesticide sprayers weighing 8 to 22 kg, which can cause neck and shoulder pain. The findings of this study have important practical ergonomic implications. Given the high prevalence of awkward postures and repetitive overhead activities during pesticide spraying, targeted ergonomic interventions should be implemented to reduce musculoskeletal strain. Engineering controls, such as lightweight backpack sprayers, adjustable harness systems, and telescopic spray wands, may help minimize sustained shoulder elevation and excessive neck extension. Administrative measures, including task rotation, scheduled rest breaks, and limiting prolonged spraying duration, could further reduce cumulative physical load. In addition, structured ergonomic training programs should be provided to farmers, particularly older workers and those with long spraying experience, to promote safe work techniques, stretching exercises, and early recognition of musculoskeletal symptoms. Community-based health promotion strategies may also enhance awareness and encourage sustainable adoption of ergonomic practices in agricultural settings.

Conclusion

This study suggests an extremely high risk from work postures of durian farmers during pesticide spraying. Awkward postures of durian farmers during pesticide spraying involve prolonged standing, carrying heavy loads, repeated movements, forceful gripping, bending neck and trunk upward, and raising shoulder. Moreover, the risk level associated with the work postures of durian farmers during pesticide spraying was correlated with season, age, monthly income, pesticide spraying experience,

spraying pesticides on other plants, pesticide spraying method, frequency of pesticide spraying, and durian tree height. The findings from this study suggest that guidelines and training on adopting exercise and appropriate work postures should be provided to durian farmers. In addition, ergonomically designed pesticide spraying tools should be developed to promote the health and safety of durian farmers.

Acknowledgements

The authors would like to thank the Prince of Songkla University, Grant number SIT6202003S, for financial support to this study. The authors thank Associate Professor Dr. Seppo Karrila for language revision.

References

1. Office of Agricultural Economics, Ministry of Agriculture and Cooperatives. Agricultural statistics. Available from: https://www.oae.go.th/assets/portals/fileups/prcaidata/files/sale%20product%2062.pdf
2. The Bureau of Occupational and Environmental Diseases, Ministry of Public Health. The report of disease and health from occupation and environment in 2018. Bangkok, Thailand. 2018. Available from: https://ddc.moph.go.th/law.php?law=5
3. Swangnetr M, Kaber DB, Puntumetakul R, Gross MT. Ergonomics-related risk identification and pain analysis for farmers involved in rice field preparation. Work. 2014;49(1):63-71. Available from: https://doi.org/10.3233/WOR-131768
4. Thetkathuek A, Meepradit P, Sa-ngiamsak T. A cross-sectional study of musculoskeletal symptoms and risk factors in Cambodian fruit farm workers in eastern region, Thailand. Safety and Health at Work. 2018;9(2):192-202. Available from: https://doi.org/10.1016/j.shaw.2017.06.009
5. Nankongnab N, Kongtip P, Tipayamongkholgul M, Bunngamchairat A, Sitthisak S, Woskie S. Difference in accidents, health symptoms, and ergonomic problems between conventional farmers using pesticides and organic farmers. Journal of Agromedicine. 2020;25(2):158-65. Available from: https://doi.org/10.1080/1059924x.2019.1607793
6. Kaewdok T, Sirisawasd S, Taptagaporn S. Work posture assessment among elderly farmers in Pathumthani province, Thailand. Journal of Advances in Health and Medical Sciences. 2018;4(1):9-14. Available from: https://www.researchgate.net/publication/331345603_Work_posture_assessment_among_elderly_farmers_in_Pathumthani_Province_Thailand
7. Saksorngmuang P, Kaewboonchoo O, Ross R, Boonyamalik P. Working hazards and health problems among rubber farmers in Thailand. Walailak Journal of Science and Technology. 2020;17(3):222-36. Available from: https://doi.org/10.48048/wjst.2020.6075
8. Nawi NSM, Deros BM, Nordin N. Assessment of Oil palm fresh fruit bunches harvesters working postures using REBA. Advanced Electron Forum. 2013;10:122-7. Available from: https://doi.org/10.4028/www.scientific.net/AEF.10.122?urlappend=%3Futm_source%3Dresearchgate.net%26utm_medium%3Darticle
9. Ng YG, Shamsul Bahri MT, Irwan Syah MY, Hashim Z, Deros BM, Abu Bakar S, et al. Risk factors of musculoskeletal disorders among oil palm fruit harvesters during early harvesting stage. Annals of Agricultural and Environmental Medicine. 2015;22:286-92. Available from: https://doi.org/10.5604/12321966.1152101
10. Azmon H, Mail MF, Nordin MN, Basri MSH, Rahman NA, Rahim SAA. Ergonomic evaluation of maize seeding using conventional method and lightweight motorized maize seeder. Advances in Agricultural and Food Research Journal. 2021;2(2):1-16. Available from: https://doi.org/10.36877/aafrj.a0000231
11. Sari AD, Pusfitasari N, Rahma R. Design and evaluation new rice planter tool without mechanical engine for improving conventional farmer's posture as revival of agriculture's Indonesia. Advanced Engineering Forum. 2013;10:116-21. Available from: https://doi.org/10.4028/www.scientific.net/AEF.10.11

6?urlappend=%3Futm_source%3Dresearchgate.net%26utm_medium%3Darticle

12. Widyanti A. Ergonomic checkpoint in agriculture, postural analysis, and prevalence of work musculoskeletal symptoms among Indonesian farmers: Road to safety and health in agriculture. Jurnal Teknik Industri. 2018;20(1):1-10. Available from: https://doi.org/10.9744/jti.20.1.1-10

13. Eka AA, Yuli AG, Agripina HA, Hari P. Farmer's work posture analysis of affected musculoskeletal disorders. Advances in Intelligent Systems Research. 2019;173:192-5. Available from: https://doi.org/10.2991/icoemis-19.2019.27

14. Muhith A, Fatmawati A, Mawaddah N, Saputra MH. Work position and low back pain in elderly farmer. 3rd International nursing conference. 4-5 November 2017. Royal hotel jember, East Java-Indonesia. Available from: https://garuda.kemdiktisaintek.go.id/documents/detail/1206345

15. Hayati A, Marzban A, Leylizadeh M. Discovering the physical onerous activities in manual sesame seed harvest using postural analysis. Agricultural Engineering International. 2018;20(4):126-31. Available from: https://cigrjournal.org/index.php/Ejounral/article/view/4987

16. Hasheminejad N, Choobineh A, Mostafavi R, Tahernejad S, Rostami M. Prevalence of musculoskeletal disorders, ergonomics risk assessment and implementation of participatory ergonomics program for pistachio farm workers. La Medicina del Lavoro. 2021;112(4):292-305. Available from: https://doi.org/10.23749/mdl.v112i4.11343

17. Velasquez S, Valderrama S, Giraldo D. Evaluation assessment of natural rubber processing in plantations and small enterprises. Ingeniería y Competitividad. 2016;18(2):233-46. Available from: https://doi.org/10.25100/iyc.v18i2.2171

18. Gomez-Galan M, Perez-Alonso J, Callejon-Ferre AJ, Hermosilla-Lopez JS. Assessment of postural load during melon cultivation in Mediterranean greenhouse. Sustainability. 2018;10(8):2729. Available from https://doi.org/10.3390/su10082729

19. Hignett S, Atamney ML. Rapid Entire Body Assessment. J. Applied Ergonomics. 2000;31:201-5. Available from: https://doi.org/10.1016/s0003-6870(99)00039-3

20. Kang F, He Z, Feng B, Qu W, Zhang B, Wang Z. Prevalence and risk factors for MSDs in vegetable greenhouse farmers: a cross-sectional survey from Shandong rural area, China. La Medicina del Lavoro. 2021;112(5):377-86. Available from: https://doi.org/10.23749/mdl.v112i5.11490

21. Ng YG, Shamsul Bahri MT, Irwan Syah MY, Mori I, Hashim Z. Ergonomics observation: Harvesting tasks at oil palm plantation. The Journal of Occupational Health. 2014;55(5):405-14. Available from: https://doi.org/10.1539/joh.13-00 17-FS

22. Deros BM, Khamis NK, Mohamad D, Kabilmiharbi N, Daruis DD. Investigation of oil palm harvesters' postures using RULA analysis. IEEE EMBS Conference on Biomedical Engineering and Sciences. 2014. Available from: https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7047504

23. Deros BM, Ali MH, Mohamad D, Daruis DDI. Ergonomic risk assessment on oil palm industry workers. Iranian Journal of Public Health. 2016;45(1):44-51. Available from https://ijph.tums.ac.ir/index.php/ijph/article/view/6153

24. Bhuanantanondh P, Buchholz B, Arphorn S, Kongtip P, Woskie S. The prevalence of and risk factors associated with musculoskeletal disorders in Thai oil palm harvesting workers: A cross-sectional study. International Journal of Environmental Research and Public Health. 2021;18(10):1-10. Available from https://doi.org/10.3390/ijerph18105474

25. Kalra S, Arora B, Pawaria S. Cross sectional survey of work-related musculoskeletal disorders and associated risk factors among female farmers in rural areas of Haryana, India. The Indian Journal of Physiotherapy & Occupational Therapy. 2016;10:149-54. Available from https://doi.org/10.5958/0973-5674.2016.00066.6

26. Vyas R. Ergonomics assessment of prevalence of musculoskeletal disorders among Indian agricultural

workers. Journal of Ergonomics. 2014;S4:1-4. Available from: https://www.longdom.org/open-access/ergonomic-assessment-of-prevalence-of-musculoskeletal-disorders-among-indian-agricultural-workers-21048.html

27. Elliott KC, Lincoln JM, Flynn MA, Levin JL, Smidt M, Dzugan J, et al. Working hours, sleep, and fatigue in the agriculture, forestry, and fishing sector: A scoping review. American Journal of Industrial Medicine. 2022;65(11):898–912. Available from: https://doi.org/10.1002/ajim.23418

28. Basher A, Nath P, Siddique ZS, Rahman MH, Rubel MA, Sayed MS, et al. Musculoskeletal disorder (MSD) among agricultural workers. Mymensingh Medical Journal. 2015;24(1):1-8. Available from: https://pubmed.ncbi.nlm.nih.gov/25725661/

29. Jain R, Meena ML, Dangayach GS, Bhardwaj AK. Association of risk factors with musculoskeletal disorders in manual-working farmers. Arch. Environ. Occup. Health. 2018;73(1):19-28. Available from: https://doi.org/10.1080/19338244.2017.1289890

30. Baksh KS, Ganpat W, Narine LK. Occupational health and safety issues among vegetable farmers in Trinidad and the implications for extension. Journal of Agricultural Safety and Health. 2015;21:159-71. Available from: https://doi.org/10.13031/jash.21.11060

31. Jain R, Meena ML, Dangayach GS, Bhardwaj AK. Risk factors for musculoskeletal disorders in manual harvesting farmers of Rajasthan. Industrial Health. 2018;56:241–8. Available from: https://doi.org/10.2486/indhealth.2016-0084

32. Trask C, Bath B, McCrosky J, Lawson J. A profile of farmers and other employed Canadians with chronic back pain: A population-based analysis of the 2009-2010 Canadian community health surveys. The Journal of Rural Health. 2014;30:300–10. Available from: https://doi.org/10.1111/jrh.12062

33. Kang MY, Lee MJ, Chung H, Shin DH, Youn KW, Im SH, et al. Musculoskeletal disorders and agriculture risk factors among Korean farmers. Journal of Agromedicine. 2016;21(4):353-63. Available from: https://doi.org/10.1080/1059924x.2016.1178612

34. Kongtawelert A, Buchholz B, Sujitrarath D, Laohaudomchok W, Kongtip P, Woskie S. Prevalence and factors associated with musculoskeletal disorders among Thai burley tobacco farmers. International Journal of Environmental Research and Public Health. 2022;19:6779. Available from: https://doi.org/10.3390/ijerph19116779

35. Kadam YR, Patil SA, Mane AS, Gore AD, Dhumale GB. The Prevalence and health impact of musculoskeletal disorders among farmers. Medical Journal. 2018;11(6):485-91. Available from: https://www.researchgate.net/publication/328950199_The_prevalence_and_health_impact_of_musculoskeletal_disorders_among_farmers

36. Xiao H, McCurdy SA, Stoecklin-Marois MT, Li CS, Schenker MB. Agricultural work and chronic musculoskeletal pain among Latino farm workers: The MICASA study. American Journal of Industrial Medicine. 2013;56(2):216-25. Available from: https://doi.org/10.1002/ajim.22118

37. Bimali I, Vongsirinavarat M, Krityakiarana W, Mathiyakom W. Factors associated with shoulder pain and disability among Nepalese farmers. International Journal of Occupational Safety and Health. 2025;15(1):37-46. Available from: https://doi.org/10.3126/ijosh.v15i1.71058

38. Swangnetr M, Kaber DB, Puntumetakul R, Gross MT. Ergonomics-related risk identification and pain analysis for farmers involved in rice field preparation. Work. 2014;49(1):63–71. Available from: https://doi.org/10.3233/WOR-131768

39. Kang MY, Lee MJ, Chung H, Shin DH, Youn KW, Im SH, et al. Musculoskeletal disorders and agricultural risk factors among Korean farmers. J. Agromed. 2016;21(4):353–63. Available from: https://doi.org/10.1080/1059924X.2016.1178612

40. Lee HJ, Oh JH, Yoo JR, Ko SY, Kang JH, Lee SK, et al. Prevalence of low back pain and associated risk factors among farmers in Jeju. Safety and Health at Work. 2021;12(4):432-8. Available from: https://doi.org/10.1016/j.shaw.2021.06.003

41. Sombatsawat E, Luangwilai T, Ong-artborirak P, Siriwong W. Musculoskeletal disorders among rice

farmers in Phimai District, Nakhon Ratchasima Province, Thailand. Emerald Insight. 2019;33(6):494-503. Available from: https://doi.org/10.1108/JHR-01-2019-0009

42. Buranatrevedh S, Sweatsriskul P. Model development for health promotion and control of agriculture occupational health hazards and accidents in Pathumthani, Thailand. Industrial Health. 2005;43(4):669-76. Available from: https://doi.org/10.2486/indhealth.43.669
43. Kotowski SE, Davis KG, Kim H, Lee KS. Identifying risk factors of musculoskeletal disorders on Korean farms. Work. 2014;49(1):15–23. Available from: https://doi.org/10.3233/wor-141921
44. Simas JMM, Alencar MCB, Yamauchi LY. Musculoskeletal disorders in banana culture workers. Brazilian Journal of Pain. 2020;3(1):33-6. Available from: https://doi.org/10.5935/2595-0118.20200008
45. Pal A, Dhara PC. Work related musculoskeletal disorders and postural stress of the women cultivators engaged in uprooting job of rice cultivation. Indian Journal of Occupational and Environmental Medicine. 2018;22(3):163–9. Available from: https://pmc.ncbi.nlm.nih.gov/articles/PMC6309355/
46. Barr AE, Barbe MF, Clark BD. Work-related musculoskeletal disorders of the hand and wrist: Epidemiology, pathophysiology, and sensorimo- tor changes. Journal of Orthopaedic and Sports Physical Therapy. 2004;34(10):610-27. Available from: https://doi.org/10.2519/jospt.2004.34.10.610

International Journal of Occupational Safety and Health

ISSN: 2091-0878 (Online) ISSN: 2738-9707 (Print)

Original Article

Improving occupational safety through the implementation of a management system based on ISO 45001 in a primary forest processing plant – Puno, Peru

Calizaya-Llatasi FL[1], Salas-Avila DA[2], Palomino-Ascencio L[1], Apaza-Campos VR[1]

[1] Professional School of Geological Engineering, Universidad Nacional del Altiplano (UNA), Puno, Perú.

[2] Professional School of Metallurgical Engineering, Universidad Nacional del Altiplano (UNA), Puno, Perú.

Corresponding author:
Fanny Luz Calizaya Llatasi,
Lecturer, Professional School of Geological Engineering, Universidad Nacional del Altiplano (UNA), Puno, Peru.
E-mail: fanny.calizaya@unap.edu.pe
Tel.: +51941470525
ORCID ID: https://orcid.org/ 0000-0002-2744-1063

Date of submission: 11.10.2025
Date of acceptance: 11.04.2026
Date of publication: 15.04.2026
Conflicts of interest: None
Supporting agencies: Universidad Nacional del Altiplano (UNA)

DOI:https://doi.org/10.3126/ijosh.v16i1.85182

Copyright: This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License

ABSTRACT

Introduction: This study assessed the impact of implementing an Occupational Health and Safety Management System (OHSMS) based on ISO 45001:2018 at a primary forest processing facility in Puno, Peru—an industrial site characterized by high occupational risks.

Methods: A quasi-experimental design with pre-test and post-test measurements was applied to a census of 37 employees (n=37). Data collection involved a 22-item structured survey mapped to the ISO 45001 clauses, the IPERC matrix for risk assessment, and direct observations.

Results: Post-intervention results showed significant improvements ($p < 0.001$) across all clauses, with safety perception increasing by 45%, leadership participation by 41%, and proper use of personal protective equipment by 52%. The most significant progress was observed in Planning ($Z = 4.47$), Support ($Z = 4.99$), and Performance Evaluation ($Z = 4.55$).

Conclusion: Implementing ISO 45001:2018 produced measurable advancements in preventive culture and risk mitigation. These findings provide empirical support for adopting the standard in Small and Medium-sized Enterprises (SMEs) within developing economies

Keywords: ISO 45001; Occupational Safety; Forest Industry; Risk Management; Peru

Introduction

Work is the means through which individuals meet their basic needs, pursue personal goals, and actively contribute to society.[1] However, in this context, occupational health and safety (OHS) remains a critical challenge. Research indicates that workplace accidents are frequently linked to human factors and a lack of systematic interventions.[2–4] emphasizing the urgent need for structured prevention strategies.[5] This situation is particularly critical in industries where workers face daily hazards that affect health and productivity, such as the forest processing sector.[6–9]

To address these risks, implementing an Occupational Health and Safety Management System (OHSMS) based on ISO 45001 ensures compliance with legal requirements and improves the efficiency of accident prevention.[10–13] Furthermore, complementary tools such as the IPERC matrix (Hazard Identification, Risk Assessment, and Control Measures) allow organizations to systematically identify hazards

and have been shown to significantly reduce risk levels.[14–21] In the Peruvian context, Law No. 29783 provides the mandatory guidelines for OHS implementation.[22,] serving as the essential foundation for policies protecting worker well-being in the region.[23–27]

Research Gap: While the benefits of OHS systems and digital tools are increasingly recognized in the literature. [28–32] There is a notable lack of empirical research regarding the practical application of ISO 45001 in Small and Medium-sized Enterprises (SMEs) within high-risk sectors in Latin American developing economies. This study addresses this gap by providing quantitative evidence of the standard's efficacy in a primary forest processing plant in the Peruvian Andes.

Methods

The study was conducted at the primary forest processing plant of Corporación Caliz S.A.C., located in an industrial zone in the district of Puno, Peru. This location is significant because of the forest industry's relevance and its environmental and occupational safety impacts

Study Design and Population:

A quasi-experimental design with pretest and posttest measurements was used to evaluate the intervention.[33] The study population comprised a census of 37 workers (n=37), representing 100% of the operational and administrative staff. A non-probabilistic convenience sampling method was used, as the study aimed to evaluate the intervention across the entire existing workforce rather than a randomized subset. While this approach limits the generalizability of findings to the broader forestry industry, it ensures high internal validity for this specific case study.

Data collection relied on three main tools. First, a situational assessment was conducted through direct observation with a structured checklist, identifying unsafe acts, hazardous conditions, and deficiencies in PPE use, signage, and machine safeguards. Second, the IPERC matrix was applied to classify risks by severity, probability, and exposure, following National Institute for Occupational Safety and Health guidelines. Third, a 22-item survey based on ISO 45001:2018 clauses was used, with a three-point Likert scale (3 = Always, 2 = Sometimes, 1 = Never); its validity was confirmed through expert judgment, and its reliability was assessed in a pilot test. The internal reliability of the instrument was determined using Cronbach's alpha, with excellent values: Pre-test = 0.982 and Post-test = 0.977. These values exceed the recommended threshold of 0.70, confirming the instrument's internal consistency.

Intervention Procedure:

The OHSMS implementation followed the ISO 45001:2018 framework over a four-month period. The process was structured in three key phases: (1) Initial Diagnosis using the IPERC matrix and direct observation; (2) Design and Implementation, which included adopting an OHS policy, staff training, hazard control, and emergency planning; and (3) Post-implementation Evaluation, where the survey and risk assessments were repeated to measure impact.For data analysis, the normality of average scores per clause was first assessed using the Shapiro-Wilk test for both pre-test and post-test data. Since the data did not follow a normal distribution, the non-parametric Wilcoxon signed-rank test was applied to compare pre- and post-intervention results. A significance level of $p = 0.05$ was used. Additionally, effect sizes (r) were calculated for the Wilcoxon signed-rank tests to quantify the magnitude of the intervention's impact, interpreted as small (<0.3), medium (0.3–0.5), or large (>0.5). All statistical analyses were performed using the R environment (version 4.3.0), with packages such as tidyverse, readxl, openxlsx, and ggplot2 for data organization, analysis, and visualization, following similar methodological approaches used in applied occupational safety research.[34,35]

Direct Observation

The situational diagnosis conducted at Corporación Caliz S.A.C. through direct observation revealed several deficiencies in occupational safety practices. A critical finding was the absence of Personal Protective Equipment (PPE) during high-risk tasks such as handling timber logs, sharpening the band saw, and processing and storing wood. This exposed workers to musculoskeletal injuries, cuts, as well as eye and hearing damage. Infrastructure-related issues were also identified, including a lack of machine guarding, the absence of safety signage, inadequate fire protection measures, uneven flooring, and poor hygienic conditions. These deficiencies significantly increased workers' vulnerability to occupational accidents.

Table 1: Positive aspects and areas for improvement in working conditions at the primary forest processing plant

Category	Description
Positive Aspects	- The work environment has good ventilation and lighting, which enhances worker safety and comfort. - The limited space encourages communication and collaboration among employees.
Areas for Improvement	- The office has a small area, which affects comfort and functionality. - There is a lack of personal protective equipment (PPE), increasing the risk of workplace accidents. - There are no protective guards on the band saw and other equipment, posing a safety hazard. - There is a lack of safety signage and fire protection measures. - Uneven floors create tripping and falling hazards. - The electrical panel lacks proper protection, increasing the risk of electric shock.

The assessment of working conditions at the primary forest processing plant revealed both positive aspects and critical areas requiring intervention. Among the favorable elements, proper ventilation and lighting stand out, contributing to greater operational safety and thermal comfort for workers. The limited space also facilitates interaction among personnel, enhancing communication throughout the processes. However, several deficiencies were identified that compromise occupational health and safety, including the lack of personal protective equipment (PPE), the absence of guards on the band saw, and the lack of safety signage and fire prevention measures Table 1. Physical hazards were also reported due to uneven and unlevel floors, as well as electrical hazards caused by exposed installation.

IPERC Matrix

This process was carried out on-site, with the active collaboration of the company's supervisors, who contributed their valuable experience and knowledge in the identification and assessment of hazards and risks. The Hazard Identification, Risk Assessment, and Risk Control (IPERC) was conducted comprehensively, taking into account the variety of environments present in each area of the facility.

Hazard Identification, Risk Assessment, and Control Measures – Baseline Study

Management: Primary Wood Transformation Plant "Corporación Caliz S.A.C."							**Code: 002**	
Safety Manager: Fanny Luz Calizaya Llatasi							**Versión:**	
Proceso: Operacional							**Date:**	
Actividad	**Task**	**Hazard**	**Risk**	**Evaluation**	**Contról de Ingeniería**	**Control administrativo**	**Reevaluación**	**Acción de mejora**
Reception and Storage of Logs Using a Forklift	Log Unloading from the Trailer	Fall from height	Impacts and collisions		Safe unloading platform with rollers	Training; Develop unloading plan		Installation of unloading ramp
	Transfer from Trailer to Warehouse	Crushing	Musculoskeletal injuries		Lifting unloading platform	Ergonomic training on log handling		Strong and elevating carts
	Log Reception	Log slipping	Upper limb injuries		Anti-slip rollers on the platform	Uso obligatorio de huantes de protección		Implementation of platforms with handrails
Cutting and Sizing	Operate band saw machine	Machine entrapment	Limb entrapment		Guards and barriers around the machine	Mandatory use of protective gloves		Presence detection and emergency stop
	Cutting and sizing logs	Entrapment in cutting machine or equipment	Entrapments, cuts and amputations		Guard installation on cutting machine	Extensive operator training		Implementation of cranes and clamping devices
Sorting, Packaging, and Storage	Bundling wooden pieces with wire	Cuts or puncture injuries	Injuries to upper limbs		Appropriate PPE (gloves, hand tools)	Exhaustive training and instruction		Ergonomic-handled tools and/or packaging machines
	Organized storage of products	Falling stacked wood	Injuries by crushing, impacts, or entrapment		Adequate PPE (safety boots)	Safe storage procedure		Strong and elevating carts

Figure 1: Hazard identification, risk assessment, and control measures in the baseline scenario

Figure 1 presents the Hazard Identification, Risk Assessment, and Control (IPERC) matrix applied to the baseline scenario of the operational process at Corporación Caliz S.A.C.'s primary forest processing plant. This tool enabled the identification of critical tasks within the log reception, cutting, and storage activities, where significant risks such as entanglement, falls, impacts, musculoskeletal injuries, and amputations were identified. Risk levels were represented using a color-coded system (red, yellow, and green) based on severity. Among the most notable findings were high-risk levels (red) in tasks related to log handling and machinery operation, indicating deficiencies in engineering and administrative controls. For each identified hazard, control measures were proposed, including secure unloading platforms, machine guards, comprehensive training programs, mandatory PPE use, and ergonomic improvements—all aligned with the requirements of Clause 6 of the ISO 45001:2018 standard.

Ethical Considerations

The study was conducted in accordance with the ethical standards of the Universidad Nacional del Altiplano (UNA-Puno). The research protocol was reviewed and approved by the Research Ethics Committee of the Vice-Rectorate for Research (VRI) under the institutional registration number PILAR 2023-0321. Additionally, the study was institutionalized through Rectoral Resolution N° 1652-2024-R-UNA. Informed consent was obtained from all participants prior to data

collection, ensuring the voluntary nature of their participation and their right to withdraw at any time. The confidentiality of individual responses was guaranteed by anonymizing survey data, and the intervention posed no physical or psychological risk to participants.

Results

The Wilcoxon test results showed statistically significant differences between the pre-test and post-test in most clauses. The W, Z, and p significance values were calculated for each clause. Positive Z values and significant p-values ($p < 0.001$) confirm an increase in scores after the intervention. Notable improvements were observed in Clauses 6 (Planning: $Z = 4.47$, $p < 0.001$), 7 (Support: $Z = 4.99$, $p < 0.001$), and 9 (Performance Evaluation: $Z = 4.55$, $p < 0.001$). This indicates a general improvement in perceptions of occupational safety following the adoption of the ISO 45001 system.

Table 2: Wilcoxon Test Results by ISO 45001 Clauses.

Clausula	W	Z	p_valor
4. Organizational Context	84	3.38	< 0.001
5. Leadership and Worker Participation	43	4.26	< 0.001
6. Planning	15.5	4.47	< 0.001
7. Support	2	4.99	< 0.001
8. Operation	84.5	3.64	< 0.001
9. Performance Evaluation	11.5	4.55	< 0.001
10. Improvement	32	4.23	< 0.001

The Wilcoxon signed-rank test showed significant differences ($p < 0.001$) between the pre-test and post-test across all ISO 45001 clauses, with Z values ranging from 3.38 to 4.99, confirming substantial improvements in occupational safety perception following the implementation of the OHSMS.

The pre-test results revealed significant deficiencies in key aspects of occupational health and safety before the implementation of the Management System. Most questions received a high number of "Never" responses, indicating the absence of formal safety practices, limited employee involvement, and inadequate training. These findings guided the design of targeted improvement actions aligned with the ISO 45001 clauses, as detailed in Table 3. The implemented actions included developing a Hazard Identification and Risk Assessment (IPERC), strengthening leadership, providing Personal Protective Equipment (PPE), standardizing safe operating procedures, and creating emergency response plans.

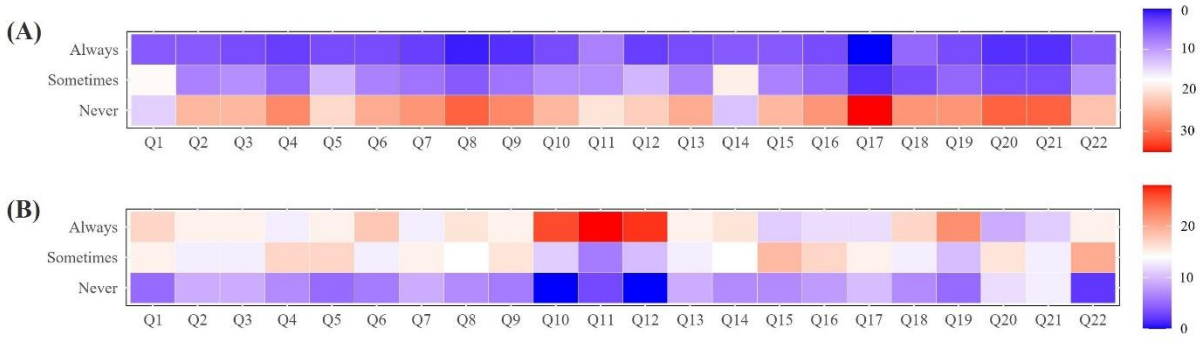


Figure 2. Frequency distribution of responses: (A) Pre-test phase and (B) Post-test phase.

These heatmaps illustrate the response frequency across 22 items for 37 workers. Darker red tones indicate higher frequency, while blue represents lower frequency. In the pre-test (Panel A), significant deficiencies were observed in items such as Q17, Q20, and Q21, where "Never" responses were prevalent. In contrast, the post-test (Panel B) shows a visual transition where red tones shifted to the "Always" category. For instance, in question Q11 (PPE use), the concentration of red tones in the "Always" row indicates consistent adherence to safety regulations.

Table 3. Comparative analysis of survey results before and after ISO 45001 implementation (n=37).

ISO 45001 Clause	Item	Question (Condensed)	Pre-test (A / S / N)*	Improvement Action Implemented	Post-test (A / S / N)*
4. Context	Q1	Informed about OHS?	5 / 18 / 14	Safety bulletins & information posters.	17 / 15 / 5
	Q2	Aware of risks?	5 / 8 / 24	Hazard identification workshops.	15 / 13 / 9
	Q3	Feedback considered?	4 / 9 / 24	Formal suggestion channel established.	15 / 13 / 9
5. Leadership	Q4	Mgt. promotes culture?	3 / 6 / 28	Visible leadership & safety meetings.	13 / 17 / 7
	Q5	Active participation?	4 / 12 / 21	Workers involved in safety committees.	15 / 17 / 5
	Q6	Suggestions heard?	4 / 8 / 25	Supervisor training on active listening.	18 / 13 / 6
6. Planning	Q7	Risks assessed before tasks?	3 / 7 / 27	IPERC applied before critical tasks.	13 / 15 / 9
	Q8	Emergency plans in place?	1 / 5 / 31	Emergency plan developed & drills conducted.	16 / 14 / 7
	Q9	Preventive measures in changes?	2 / 7 / 28	Risk analysis integrated into changes.	15 / 16 / 6
7. Support	Q10	Regular OHS training?	4 / 9 / 24	Annual training plan implemented.	26 / 11 / 0
	Q11	PPE access and use?	8 / 9 / 20	PPE supply & supervision enforced.	28 / 6 / 3
	Q12	Signs visible/clear?	3 / 12 / 22	Standardized signage installed.	27 / 10 / 0
8. Operation	Q13	Safe procedures followed?	4 / 8 / 25	Safe Operating Procedures (SOPs) implemented.	15 / 13 / 9
	Q14	Cleanliness/Order (5S)?	5 / 19 / 13	Routine cleaning & layout organization.	16 / 12 / 9
	Q15	Equipment inspection?	5 / 8 / 24	Inspection schedule & logs created.	11 / 15 / 11
	Q16	Rules followed consistently?	4 / 6 / 27	Reinforced supervision & compliance.	12 / 17 / 8

9. Perf. Eval.	Q17	Informed of audit results?	0 / 2 / 35	Audit findings shared with staff.	12 / 15 / 10
	Q18	Incidents investigated?	6 / 4 / 27	Root cause analysis applied.	18 / 13 / 7
	Q19	Improvements communicated?	4 / 6 / 27	Feedback meetings on actions taken.	22 / 10 / 5
10. Improvement	Q20	Corrective actions seen?	2 / 4 / 31	Corrective actions logged & displayed.	9 / 12 / 16
	Q21	Continuous improvement promoted?	2 / 3 / 32	Periodic progress reports & policy update.	11 / 14 / 12
	Q22	Motivated to report acts?	5 / 9 / 23	Anonymous reporting & positive reinforcement.	16 / 12 / 9

The results in Table 3 of the post-test reflect a significant improvement in workers' perception, knowledge, and application of occupational health and safety practices compared to the pre-test. This improvement is a direct result of implementing the Occupational Health and Safety Management System (OHSMS) in accordance with the requirements of ISO 45001:2018. Concrete progress was observed in key areas, including training (item Q10), where 100% of workers reported receiving instruction; access to and condition of personal protective equipment (Q11); and visibility and understanding of safety signage (Q12). These results demonstrate that the "Support" section (Clause 7) is an effective intervention, contributing to a safer environment and better working conditions. There was also a reported increase in participation in safety-related activities (Q5) and a greater appreciation of worker input by supervisors and management (Q6), indicating strengthened leadership and active involvement (Clause 5). The implementation of feedback mechanisms and consultation spaces played a key role in these advancements.

Regarding planning and operational control (Clauses 6 and 8), improvements were noted in the application of safe procedures and emergency preparedness (Q8). However, weaknesses persist in areas such as the frequency and effectiveness of technical inspections (Q15) and the timely implementation of corrective actions (Q20), with "Never" responses remaining significant. It suggests that although the system has been implemented, specific actions still require ongoing follow-up and operational reinforcement.

Concerning continual improvement (Clause 10), while there is progress in workers' perception of the company's efforts (Q21), there remains to strengthen a culture of sustained improvement. It includes institutionalizing the periodic review of results and expanding recognition and motivation mechanisms for reporting unsafe conditions (Q22). The post-test results demonstrate that implementing the OHSMS has led to positive, measurable changes in occupational safety management. Nonetheless, the findings also highlight areas that require attention during the system consolidation phase. These outcomes support the effectiveness of ISO 45001:2018 as a strategic tool for reducing risks, improving preventive culture, and protecting worker health in industrial environments such as the primary forest transformation plant.

Radar chart comparing the degree of compliance with ISO 45001:2018 clauses (Context, Leadership, Planning, Support, Operation, Performance, Improvement) between the Pre-test and Post-test is shown in Figure 3. The expansion of the plot area in the post-test demonstrates a comprehensive improvement in management system performance, particularly in Planning and Support.

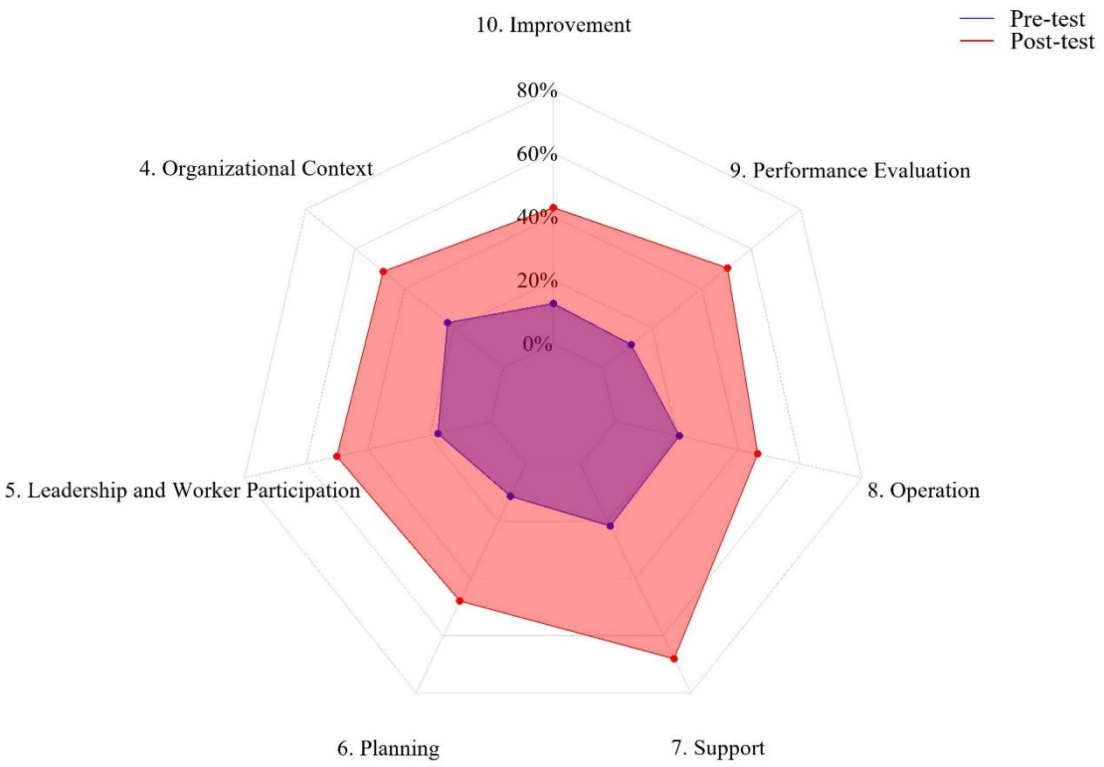


Figure 3. Comparative radar chart of compliance by ISO clause (Pre-test vs. Post-test).

Discussion

The findings of this study demonstrate that implementing the Occupational Health and Safety Management System (OHSMS) in accordance with ISO 45001:2018 led to significant improvements in safety perception, practices, and culture at the primary forestry processing plant of Corporación Caliz S.A.C. in Puno. This improvement aligns with previous studies highlighting the positive impact of this standard in similar industrial environments.[36,37,38]

Impact of ISO 45001 Clauses on Organizational Behavior. First, the pre-test analysis revealed several structural and managerial shortcomings, including a lack of visible leadership and a weak risk-reporting culture. These weaknesses are consistent with the study that argues that the lack of organizational integration in safety systems limits their effectiveness, especially in small and medium-sized enterprises (SMEs).[36] The intervention effectively addressed these critical areas. The emphasis on Leadership and Worker Participation (Clause 5) fostered a positive organizational shift, aligning with findings by Malinda & Soediantono, who emphasize the role of supervisors as facilitators of a preventative culture.[40] Furthermore, strengthening internal communication and participatory leadership proved key to reducing occupational accidents, as suggested by international literature.[41,42]

Operational Improvements and Risk Management The rigorous application of the IPERC matrix (Hazard Identification, Risk Assessment, and Risk Control) was crucial for prioritizing corrective actions and mitigating specific hazards.[43,44] This strategy enabled effective intervention in high-risk processes, such as machine handling (e.g., the band saw), for which incidents had been recorded prior to the intervention. Additionally, the observed effects not only benefit workers but also increase productivity and reduce losses from accidents or downtime, consistent with findings in high-risk industrial settings.[45]

Challenges in System Maturity. Despite the overall success, limitations persisted after implementation, particularly regarding perceptions of efficiency in corrective action management (Clause 10). These challenges are in line with findings that improvement actions often require more time to mature and produce sustained impacts on organizational culture.[46] This reinforces the need for ongoing training and leadership renewal, especially in the Peruvian context, where SMEs face resource constraints. Similar outcomes have been reported in forestry and industrial sectors, which found that the cultural co-creation of safety practices enhances long-term performance, while identifying managerial engagement as a key factor in risk reduction.[47,48]

Limitations and Future Directions

It is important to acknowledge certain limitations. First, the reliance on self-reported survey data introduces the risk of social desirability bias, in which workers may overreport positive behaviors to align with perceived management expectations. Second, the sample size (n=37), while representing a census of the specific plant, limits the generalizability of findings. Future research should address these gaps by employing a mixed-methods approach that triangulates perception surveys with objective data sources, such as official accident records. This approach would verify if interventions translate into lasting organizational learning rather than isolated compliance.[49]

Conclusion

The implementation of the Occupational Health and Safety Management System (OHSMS), following ISO 45001:2018, significantly strengthened the safety culture and operational discipline in the studied plant, confirming the effectiveness of structured management approaches.

The comparative pre–post design validated the system's positive impact and supports its scalability to other industrial contexts. Despite the positive outcomes, the study identified ongoing challenges in managing corrective actions and fostering a culture of continuous improvement, highlighting the need for sustained follow-up and periodic system review. It aligns with findings from other studies, which suggest that the benefits of constant improvement in management systems require time, organizational commitment, and ongoing evaluation.

Beyond the case of Puno, these findings contribute to strengthening Occupational Health and Safety (OHS) practices and policies in Latin America, where many small and medium-sized industries face similar structural limitations. The evidence obtained may inform national strategies for adopting ISO 45001 as a framework for preventive culture and institutional governance. Future research should focus on longitudinal monitoring to evaluate sustained behavioral and organizational change, as well as on integrating ISO 45001 with complementary standards such as ISO 9001 (quality management) and ISO 14001 (environmental management) to promote comprehensive, sustainable performance.

This work contributes to the scientific literature by demonstrating the tangible benefits of implementing ISO 45001:2018 in high-risk industrial environments, supporting its adoption as a key strategy for risk mitigation, accident reduction, and safer workplaces. Building on these results, future research should expand longitudinal analyses and inter-system integration to consolidate preventive management at a regional scale. Assessing the long-term impact of such interventions and their integration with other management systems (e.g., ISO 9001 for Quality, ISO 14001 for Environment) will provide a more holistic approach to organizational safety and sustainability.

Author Contributions

Conceptualization: FC, DS; Methodology: FC, LP; Formal analysis: VA, FC; Investigation: FC; Writing – original draft preparation: FC, DS; Writing – review and editing: LP, VA. All authors have read and agreed to the published version of the manuscript.

References

1. Ortega J, Rodríguez J, Hernández H. Importancia de la seguridad de los trabajadores en el cumplimiento de procesos, procedimientos y funciones. Academia & Derecho. 2017;14:155-75. Available from: https://doi.org/10.18041/2215-8944/academia.14.1490
2. Betsis S, Kalogirou M, Aretoulis G, Pertzinidou M. Work Accidents Correlation Analysis for Construction Projects in Northern Greece 2003–2007: A Retrospective Study. Safety (Basel). 2019;5(2):33. Available from: https://doi.org/10.3390/safety5020033
3. Ifelebuegu AO, Martins OA, Theophilus SC, Arewa AO. The Role of Emotional Intelligence Factors in Workers' Occupational Health and Safety Performance—A Case Study of the Petroleum Industry. Safety (Basel). 2019;5(2):30. Available from: https://doi.org/10.3390/safety5020030
4. Tormoehlen SA, Field WE. Summary of Indiana Farm Fatalities Involving Individuals 55 Years and Older—1988–2017. Safety (Basel). 2019;5(2):39. Available from: https://doi.org/10.3390/safety5020039
5. Ketsakorn A, & Kosolsaksakul P. Application of Delphi technique and analytic hierarchy process to prioritize the occupational health and safety management system requirements. International Journal of Occupational Safety and Health. 2025;15(2):182–91. Available from: https://doi.org/10.3126/ijosh.v15i2.60760
6. Tsichla K, Adam K. The Evolution of Health and Safety Training Needs of the Mining Sector in Greece and EU. Mater Proc. 2021;5(1):136. Available from: https://doi.org/10.3390/materproc2021005136
7. Shu B, Liu Y, Wang C, Zhang H, Amani-Beni M, Zhang R. Geological hazard risk assessment and rural settlement site selection using GIS and random forest algorithm. Ecol Indic. 2024;166:112554. Available from: https://doi.org/10.1016/j.ecolind.2024.112554
8. Manni V, De Merich D, Campo G. Management Approaches to Health and Safety at Work during Prevention Intervention Planning. Int J Environ Res Public Health. 2023;20(24):7142. Available from: https://doi.org/10.3390/ijerph20247142
9. Šolc M, Blaško P, Girmanová L, Kliment J. The Development Trend of the Occupational Health and Safety in the Context of ISO 45001:2018. Standards. 2022;2(3):294-305. Available from: https://doi.org/10.3390/standards2030021
10. Glevitzk I, Sârb A, Popa M. Study Regarding the Improvement of Bottling Process for Spring Waters, through the Implementation of the Occupational Health and Food Safety Requirements. Safety (Basel). 2019;5(2):32. Available from: https://doi.org/10.3390/safety5020032
11. Morgado L, Silva FJG, Fonseca LM. Mapping Occupational Health and Safety Management Systems in Portugal: outlook for ISO 45001:2018 adoption. Procedia Manuf. 2019;38:755–64. Available from: https://doi.org/10.1016/j.promfg.2020.01.103
12. Bejinariu C, Darabont DC, Burduhos-Nergis DP, Cazac AM, Chiriac-Moruzzi C. Considerations Regarding the Application of the Occupational Injury and Illness Risk Assessment Method at Workplaces/Workstations, in Relation to the ISO 45001 Standard. Sustainability. 2023;15(3):2121. Available from: https://doi.org/10.3390/su15032121
13. Ding X, Hu H, Hu Y, Jin J, Liu Z, Pan H, et al. Identification and precise control of disaster-causing hazards in metro operation and

maintenance: A new method for improving metro operation safety based on data mining. Comput Ind Eng. 2025;201:110899. Available from: https://doi.org/10.1016/j.cie.2025.110899

14. Chen Y, Sun Z, Hou Y, Gao D, Li Z. Hazard identification & risk control in aluminum production. Process Saf Environ Prot. 2022;165:336–46. Available from: https://doi.org/10.1016/j.psep.2022.07.017

15. Rodríguez-Martín M, Rodríguez-Gonzálvez P, Domingo R. Asking about Risk in a Company: A New Approach to Learning ISO 45001 in Engineering Programs. Standards. 2023;3(1):21-30. Available from: https://doi.org/10.3390/standards3010003

16. Selleck R, Hassall M, Cattani M. Determining the Reliability of Critical Controls in Construction Projects. Safety (Basel). 2022;8(3):64. Available from: https://doi.org/10.3390/safety8030064

17. Celik E, Gul M. Hazard identification, risk assessment and control for dam construction safety using an integrated BWM and MARCOS approach under interval type-2 fuzzy sets environment. Autom Constr. 2021;127:103699. Available from: https://doi.org/10.1016/j.autcon.2021.103699

18. Chopitea JA, Delgado LJ. Metodología para la identifación de peligros y evaluación de riesgos (IPER). 2014. Available from: https://alicia.concytec.gob.pe/vufind/Record/RUMP_ecf3cf35a0023dab5b6352c589d286eb/Details

19. Ismail Iqbal M, Isaac O, AI Rajawy I, Khuthbuddin S, Ameen A. Hazard identification and risk assessment with controls (Hirac) in oil industry – A proposed approach. Mater Today Proc. 2021;44(6):4898–902. Available from: https://doi.org/10.1016/j.matpr.2020.11.800

20. Medina A, Chon E, Sanches S. Identificación de Peligros y Evaluación y Control de Riesgos (IPERC) en la miniplanta de hilandería y tejeduría de la Facultad de Ingeniería Industrial Ind Data. 2016;19(1):77-88. Available from: https://doi.org/10.15381/idata.v19i1.12543

21. Miñan guillermo, Monja J, Gonzales oscar, Simpalo-Lopez WD, Castillo-Martínez WE. Gestión de riesgos implementando la ley peruana 29783 en una empresa pesquera. Gerenc Políticas Salud. 2020;41(3). Available from: http://scielo.sld.cu/scielo.php?script=sci_arttext&pid=S1815-59362020000300002

22. Perú. Decreto Supremo N° 005-2012-TR. Reglamento de la Ley N° 29783, Ley de Seguridad y Salud en el Trabajo. Diario Oficial El Peruano. 2011. Available from: https://diariooficial.elperuano.pe/Normas/obtenerDocumento?idNorma=38

23. Fagua G, De Hoz Y, Morales J. Sistema de gestión de seguridad y salud en el trabajo: una revisión desde los planes de emergencia. the safety and occupational health management system focusing on emergency Plans Ipsa Scientia. Ipsa Scientia. 2018;3(1):23–9. Available from: https://doi.org/10.25214/27114406.920

24. Bentley TA, Caponecchia C, Onnis L ann, Brunetto Y, Farr-Wharton B, Cattani M, et al. A systems model for the design of occupational health and safety management systems inclusive of work-from-home arrangements. Appl Ergon. 2023;109:103966. Available from: https://doi.org/10.1016/j.apergo.2023.103966

25. Friebel AG, Potter RE, Dollard M. Health and safety representatives' perceptions of occupational health and safety policy developments to improve work-related psychological health: Applying the theory of planned behaviour. Saf Sci. 2024;172:106410. Available from: https://doi.org/10.1016/j.ssci.2023.106410

26. Fatima SH, Rothmore P, Giles LC, Bi P. Impacts of hot climatic conditions on work, health, and safety in Australia: A case study of policies in practice in the construction industry. Saf Sci. 2023;165:106197. Available from: https://doi.org/10.1016/j.ssci.2023.106197

27. Leka S, Torres L, Jain A, Di Tecco C, Russo S, Iavicoli S. Relationship Between Occupational Safety and Health Policy Principles,

Organizational Action on Work-related Stress and the Psychosocial Work Environment in Italy. Saf Health Work. 2023;14(4):425–30. Available from: https://doi.org/10.1016/j.shaw.2023.10.001

28. Sadeghi H, Cheung CM, Yunusa-Kaltungo A, Manu P. A systematic review of occupational safety and health in modular integrated construction. Saf Sci. 2025;189:106897. Available from; https://doi.org/10.1016/j.ssci.2025.106897

29. Gonçalves A, Dutra A, Mussi CC. Occupational risks and health and safety management strategies in the port sector: A systematic literature review. Saf Sci. 2025;184:106767. Available from: https://doi.org/10.1016/j.ssci.2024.106767

30. Knobel P, Naweed A. How does the regulatory context influence systems thinking in work health and safety (WHS) inspectors? Saf Sci. 2023;166:106237. Available from: https://doi.org/10.1016/j.ssci.2023.106237

31. Zorzenon R, Lizarelli FL, Daniel DBA. What is the potential impact of industry 4.0 on health and safety at work? Saf Sci. 2022;153:105802. Available from: https://doi.org/10.1016/j.ssci.2022.105802

32. Jarota M. Artificial intelligence in the work process. A reflection on the proposed European Union regulations on artificial intelligence from an occupational health and safety perspective. Comput Law Secur Rev. 2023;49:105825. Available from: https://doi.org/10.1016/j.clsr.2023.105825

33. Bell BA. Post-test Design. Encyclopedia of Research Design. Thousand Oaks: SAGE Publications. 2010:1087–91. Available from: https://doi.org/10.4135/9781412961288.n305

34. Karanikas N, Zerguine H. Redefining health, risk, and safety for occupational settings: A mixed-methods study. Saf Sci. 2025;181:106698. Available from: https://doi.org/10.1016/j.ssci.2024.106698

35. Vitrano G, Micheli GJL. National occupational safety and health systems: Exploring the underlying networks for future sustainable development. Sustain Futures. 2024;8:100382. Available from: https://doi.org/10.1016/j.sftr.2024.100382

36. Otitolaiye VO, Abd Aziz FS, Munauwar M, Omer F. The Relationship Between Organizational Safety Culture and Organization Safety Performance. The Mediating Role of Safety Management System. Int J Occup Saf Health. 2021 Sep 30;11(3):148–57. Available from: https://doi.org/10.3126/ijosh.v11i3.39766

37. Mixafenti S, Moutzouri A, Karagkouni A, Sartzetaki M, Dimitriou D. Assessment of Occupational Health and Safety Management: Implications for Corporate Performance in the Secondary Sector. Safety (Basel). 2025;11(2):44. Available from: https://doi.org/10.3390/safety11020044

38. Chatzoglou PD, Kotzakolios AE, Marhavilas PK. Health and Safety Management System (HSMS) and Its Impact on Employee Satisfaction and Performance—A New HSMS Model. Safety (Basel). 2025;11(2):52. Available from: https://doi.org/10.3390/safety11020052

39. Mohandes SR, Karasan A, Gündoğdu FK, Singh AK, Mahdiyar A, Poor Sabet PG, et al. Occupational safety and health risk assessment during maintenance stage of construction projects: A multi-pronged fuzzy-based approach. Expert Syst Appl. 2025;280:127522. Available from: https://doi.org/10.1016/j.eswa.2025.127522

40. Malinda A, Soediantono D. Benefits of Implementing ISO 45001 Occupational Health and Safety Management Systems and Implementation Suggestion in the Defense Industry: A Literature Review. J Ind Eng Manag Res. 2022;3(2):35-47. Available from: https://jiemar.org/index.php/jiemar/article/view/274

41. No HW, Cha WC. An Integrated Framework for Implementing Safety-I and Safety-II Principles in Aviation Safety Management. Safety (Basel). 2025;11(2):56. Available from: https://doi.org/10.3390/safety11020056

42. Berglund L, Johansson J, Johansson M, Nygren M, Stenberg M. Structures and Processes for Safety

Culture? Perspectives from Safety Leaders in the Swedish Construction Industry. Safety (Basel). 2025;11(2):47. Available from: https://doi.org/10.3390/safety11020047

43. Milošević I, Stojanović A, Nikolić Đ, Mihajlović I, Brkić A, Perišić M, et al. Occupational health and safety performance in a changing mining environment: Identification of critical factors. Saf Sci. 2025;184:106745. Available from: https://doi.org/10.1016/j.ssci.2024.106745

44. Bérubé M, Chatigny C, Laberge M. Gender differences in occupational health and safety perceptions: Insights from youth in dual vocational training. Saf Sci. 2025;186:106797. Available from: https://doi.org/10.1016/j.ssci.2025.106797

45. Topazian RJ, Wec A, Ali J, Frattaroli S, Locke P, Taylor JA, et al. The value of occupational health and safety data: Perceptions of current data practices in the fire service. J Safety Res. 2025;94:120–7. Available from: https://doi.org/10.1016/j.jsr.2025.06.016

46. Linden A, Barth H, Ulvenblad P, Karlsson E, Rwamamara R. Mechanisms and Driving Forces of Safety Culture Co-Creation in the Forest Industry. Safety (Basel). 2025;11(2):45. Available from: https://doi.org/10.3390/safety11020045

47. Aguirre A. Manejo forestal en el siglo XXI. Madera Bosques. 2015;21Spec:17–28. Available from: https://www.scielo.org.mx/scielo.php?script=sci_arttext&pid=S1405-04712015000400002

48. Cruz J, Altamirano E, Villegas C, Núñez L. Especies forestales maderables y su utilidad en biotecnología y medicina. Rev Investig Talentos. 2024;11(1):15–31. Available from: https://dialnet.unirioja.es/servlet/articulo?codigo=9617612

49. Mai NC, Kato T. Designing a Short Disaster Risk Reduction Course for Primary Schools: An Experimental Intervention and Comprehensive Evaluation in Hue City, Vietnam. Safety. 2025 Jul 3;11(3):64. Available from: https://doi.org/10.3390/safety11030064

International Journal of Occupational Safety and Health

ISSN: 2091-0878 (Online) ISSN: 2738-9707 (Print)

Original Article

Longitudinal trajectories of noise-induced hearing loss in a municipal workforce: a pilot study of diagnostic migration (2023–2025)

Goskolli P[1], Kalkavouris N[1], Karaiskos C[1], Makrynos G[1], Mikelopoulou P[2], Farantos I[3], Dounias G[1]

[1]Department of Public Health Policy, School of Public Health, University of West Attica, Athens, Greece

[2]Health Inspector, Municipality of Keratsini, Greece

[3]University of Patras, Pátrai, West Greece, Greece

Corresponding author:
Goskolli Petri
OEM Resident Physician,
Department of Public Health Policy,
School of Public Health,
University of West Attica,
Athens, Greece
E-mail: petrogoskolli@gmail.com
Tel.: +306944978816

ORCID ID: https://orcid.org/0009-0000-2963-2616

Date of submission: 30.12.2025
Date of acceptance: 04.04.2026
Date of publication: 15.04.2026

Conflicts of interest: None
Supporting agencies: None
DOI:https://doi.org/10.3126/ijosh.v16i1.88416

Copyright: This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License

ABSTRACT

Introduction: Noise-Induced Hearing Loss (NIHL) remains a prevalent occupational health issue in industrial sectors. This study aimed to evaluate the longitudinal changes in hearing thresholds in municipal workers exposed to noise levels exceeding 85 dB(A) and to assess the impact of specific risk stratification on auditory health.

Methods: A Pilot Retrospective Longitudinal Cohort Study was conducted on 23 of 44 eligible male municipal workers who completed both surveillance cycles over a two-year period (2023–2025). The participants were stratified into Group A (Gardeners, n=5) and Group B (Drivers, n=18) categories based on job profiles. Pure-tone audiometry was analyzed according to Health and Safety Executive (HSE 2021) guidelines. Statistical analysis included the Wilcoxon signed-rank test for longitudinal within-subject comparisons and the Mann–Whitney U and Fisher's Exact tests for between-group analyses.

Results: The cohort exhibited a statistically significant deterioration in mean hearing thresholds over the study period. Wilcoxon signed-rank test comparing mean high-frequency thresholds (3–4–6 kHz) between 2023 and 2025 yielded $p < 0.001$. By 2025, 47.8% (n=11) of the workforce met the criteria for clinical referral (Category 3). All workers in Group A (5/5, 100%) progressed to Category 3, compared to 6/18 workers (33.3%) in Group B.

Conclusion: Group A demonstrated significantly accelerated hearing loss compared to drivers (B), validating the need for stratified risk management. The findings support the implementation of a shortened 6-month audiometric review cycle for high-risk occupational groups.

Keywords: Audiometry, hearing loss, municipal workers, noise.

Introduction

Occupational noise exposure remains a significant challenge for public health and occupational medicine globally.[1,2] In municipal work environments, employees are often subjected to fluctuating but persistent noise levels from heavy machinery, waste management vehicles, and maintenance equipment. Despite regulatory efforts, noise-induced hearing loss (NIHL) remains among the most common work-related illnesses.[3,4]

Chronic exposure to noise levels exceeding 85 dB(A) is the leading cause of sensorineural hearing loss, typically characterized by a distinctive "notch" in high-frequency auditory thresholds.[5,6] However, the impact of noise extends beyond the cochlea. Chronic noise acts as

a systemic stressor that correlates with reduced quality of life,[7] and occupational burnout.[8] Furthermore, a growing body of epidemiological evidence links long-term noise exposure to non-auditory health effects, including cardiovascular disease,[9] hypertension, and sleep disturbance.[10,11] The World Health Organization estimates that the burden of disease from occupational noise is substantial, necessitating rigorous surveillance protocols.[12]

For the effective management of these workers, the Health and Safety Executive (HSE) categorization system provides a standardized, age-corrected framework for auditory health surveillance.[13] Consistent with European Directive 2003/10/EC, this system classifies hearing health into levels of increasing severity, helping to differentiate between natural presbycusis and noise-induced trauma.[14,15] The strength of the HSE scheme lies in its ability to detect significant shifts over time, identifying workers at risk of rapid deterioration.[13,16]

This study utilized a retrospective longitudinal design to analyze routine occupational health surveillance data collected from a cohort of municipal workers between 2023 and 2025. By detailing these specific cases, this study aims to validate the use of HSE surveillance in municipal settings and advocate for integrated health monitoring to preserve the auditory integrity of the workforce.[17,18]

Methods

This pilot retrospective longitudinal cohort study analyzed routine occupational audiometric surveillance data from male municipal workers exposed to occupational noise levels exceeding 85 dB(A). Of an initial pool of 44 eligible workers, 23 completed audiometric testing during both the 2023 and 2025 surveillance cycles and were included in the final analysis.

Pure-tone air-conduction audiometry was performed in an acoustically controlled environment by trained personnel. To ensure data reliability and adherence to international standards, audiometers underwent biological checks and annual calibration in accordance with the ISO 8253-1 and ISO 389 reference standards. Bilateral thresholds were measured at 1, 2, 3, 4, 6, and 8 kHz. All audiograms were retrospectively reviewed by a qualified occupational physician to confirm HSE categorization and clinical referral status.

Hearing status was classified using the Health and Safety Executive (HSE 2021) age-adjusted categorization system: Category 1 (acceptable hearing), Category 2 (warning), and Category 3 (poor hearing requiring referral). For this study, Category 3 cases were further subclassified as 3A (rapid high-frequency loss), 3B (progressive loss involving speech frequencies), or 3C (asymmetric loss). Rapid hearing loss was defined as an aggregate threshold increase of ≥30 dB(A) across the 3, 4, and 6 kHz frequencies over the two-year surveillance interval. This threshold aligns with HSE criteria for accelerated deterioration. The HSE 2021 framework was selected as the primary risk stratification tool due to its structured age-adjusted thresholds and compatibility with UK occupational health surveillance. Its categorization is broadly comparable to international hearing conservation approaches, including ISO-based methodologies and NIOSH-referenced surveillance standards. This enhances the interpretability and applicability of our findings for occupational settings beyond the UK.

Additionally, it was determined that objective data regarding hearing protection device (HPD) compliance (e.g., fit-testing results or logged usage) and non-occupational noise exposure (e.g., recreational noise or secondary employment) were not consistently recorded. Consequently, these variables could not be included in the statistical models, and their potential role as confounders is acknowledged as a limitation on the study's ability to establish definitive causality.

Longitudinal changes were analyzed using the Wilcoxon signed-rank test given the non-normal

distribution of audiometric data. Between-group comparisons were performed using the Mann–Whitney U test for continuous variables and Fisher's Exact test for categorical variables. These non-parametric tests were specifically selected to ensure statistical robustness given the small sample size of Group A (n=5). Statistical significance was set at $p < 0.05$.

All procedures performed in this study involving human participants were conducted in accordance with the ethical standards of the responsible institutional committee and with the principles of the Declaration of Helsinki (1964), as revised in 2013.

The study utilized retrospective occupational health surveillance data collected as part of routine workplace health monitoring. All data were anonymized prior to analysis to ensure participant confidentiality.

This study was conducted and reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines for cohort studies.

Results

An initial cohort of 44 noise-exposed municipal workers was identified through the surveillance program. However, inclusion required complete audiometric datasets for both the 2023 and 2025 surveillance cycles. Consequently, 21 individuals were excluded due to missed appointments, employment termination, or incomplete clinical records, resulting in a final study sample of N=23. This represents a retention rate of 52.3%. Basic demographic and clinical characteristics of excluded workers were not consistently available across records; therefore, a formal comparison with the final cohort could not be reliably performed. However, exclusions were primarily due to administrative reasons (missed appointments, employment termination, or incomplete documentation) rather than audiometric severity.

The median age of the cohort was 44.0 years (range: 22–62 years), reflecting a workforce with established occupational tenure.

Based on work categories, participants were divided into two groups:

-Group A (Gardeners): 21.7% (n=5) of the cohort.

-Group B (Drivers): 78.3% (n=18) of the cohort.

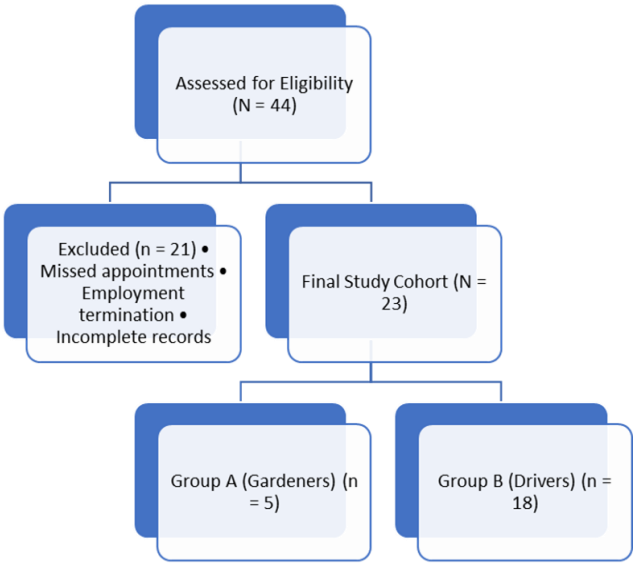


Figure 1. Flow diagram of participant selection. Of the initial 44 workers identified, 21 were excluded due to incomplete longitudinal data, resulting in a final analytical cohort of 23 workers stratified into occupational groups.

Regarding clinical co-factors, 47.8% (n=11) of the participants were smokers, and 34.8% (n=8) were classified as obese (BMI >30).

Longitudinal tracking of HSE categories revealed a clear diagnostic migration toward higher impairment levels over the two-year period.

Longitudinal analysis indicates that this category failed to act as a stable plateau for the high-risk subgroups. By the 2025 follow-up, 70% (n=7) of the workers originally classified in Category 2 had deteriorated further into Category 3 (Referral). Consequently, the prevalence of

Category 3 cases in the total cohort surged to 47.8% (n=11) by the end of the study ($p < 0.001$).

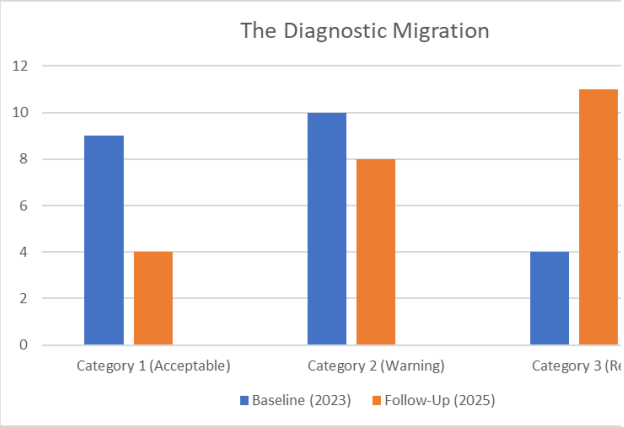


Figure 2. Longitudinal diagnostic migration of HSE Hearing Categories (2023–2025).

The graph illustrates a significant shift in the workforce distribution, with a marked reduction in Category 1 (Acceptable) cases and a corresponding surge in Category 3 (Referral) cases to 47.8% (n=11) by the end of the surveillance period.

Table 1: Individual Audiometric Progression and HSE Categorization

Worker	Exposure Group	HSE Category (2023)	HSE Category (2025)	High-Frequency Change (3–4–6 kHz)	Rapid Loss (≥30 dB(A))	Final Sub-category
1	B	1	2	Mild increase	No	–
2	B	1	1	Stable	No	–
3	B	1	1	Stable	No	–
4	B	1	2	Mild increase	No	–
5	B	2	2	Stable	No	–
6	B	2	**3**	Marked increase	Yes	**3A**
7	B	1	1	Stable	No	–
8	B	1	2	Mild increase	No	–
9	B	2	2	Stable	No	–
10	B	2	**3**	High-frequency worsening	Yes	**3A**
11	A	2	**3**	Pronounced increase	Yes	**3A**
12	B	2	2	Stable	No	–
13	B	1	1	Stable	No	–
14	B	1	2	Mild increase	No	–
15	B	3	**3**	Further worsening	No	**3B**
16	A	2	**3**	Pronounced increase	Yes	**3A**
17	B	2	**3**	High-frequency loss	Yes	**3A**
18	B	3	**3**	Stable severe loss	No	**3B**
19	B	1	2	Mild increase	No	–
20	A	2	**3**	Pronounced increase	Yes	**3A**
21	A	3	**3**	Progressive loss	No	**3B**
22	B	3	**3**	Stable	No	**3B**
23	A	2	**3**	Pronounced increase	Yes	**3A**

The analysis identified a polarization in auditory outcomes between the two occupational groups, establishing Group A as the higher-risk occupational group. It exhibited absolute

deterioration. No worker in this group remained in the Acceptable or Warning categories.

In contrast, Group B demonstrated significantly higher auditory resilience. Only 6/18 workers (33.3%) progressed to Category 3.

Fisher's Exact Test confirmed that membership in Group A was significantly associated with progression to clinical referral status ($p = 0.042$). Additionally, the Mann-Whitney U test confirmed that the magnitude of threshold shifts was significantly higher in Group A compared to B ($p = 0.038$).

Table 2. Group Comparison: Exposure Group A vs. B

Variable	Group A (Gardeners) (n=5)	Group B (Drivers) (n=18)	p-value
Referral Rate (Category 3)	5/5 (100%)	6/18 (33.3%)	**0.042**
Rapid Loss sub-category (3A)	4/5 (80%)	3/18 (16.7%)	–
Median Threshold Shift	Higher Magnitude	Lower Magnitude	**0.038**

Beyond noise exposure, the study evaluated the prevalence of synergistic risk factors—specifically Smoking, Obesity (BMI >30), and Hypertension—across the cohort.

Despite the visible trend indicating a "heavier" clinical profile for Group A, these differences did not reach statistical significance (Smoking: $p = 0.62$; Hypertension: $p = 0.54$; Obesity: $p > 0.99$). This lack of statistical confirmation is attributable to the limited sample size (n=23), which restricts the power to detect secondary associations. However, the qualitative clustering of these factors within the rapid-progression group (A) warrants clinical attention.

Table 3. Comparative Table of Clinical and Demographic Factors

Variable	Group A (Gardeners) (n=5)	Group B (Drivers) (n=18)	Total Cohort (N=23)
Median Age (Years)	46.0	43.5	44.0
Smoking Status			
Smokers (*n*)	3 (60.0%)	8 (44.4%)	11 (47.8%)
Non-Smokers (*n*)	2 (40.0%)	10 (55.6%)	12 (52.2%)
BMI Status:			
Obese (>30)	2 (40.0%)	6 (33.3%)	8 (34.8%)
Non-Obese (< 30)	3 (60.0%)	12 (66.7%)	15 (65.2%)
Hypertension:			
Present (*n*)	2 (40.0%)	4 (22.2%)	6 (26.1%)
Absent (*n*)	3 (60.0%)	14 (77.8%)	17 (73.9%)
Final HSE Outcome (2025)			
Category 3 (Referral)	**5 (100%)**	**6 (33.3%)**	**11 (47.8%)**

Discussion

This study demonstrates a rapid deterioration in auditory health within the municipal workforce from 2023 to 2025. Similar findings have been reported in occupational health studies published in the International Journal of Occupational Safety and Health. Patel and Ghosh documented significantly high-frequency hearing threshold shifts among weaving factory workers exposed to elevated noise levels, particularly in the 4–6 kHz frequency range, which is a characteristic audiometric pattern of noise-induced hearing loss.[19] The high proportion of workers meeting HSE 2021 Category 3 referral criteria (47.8%, n=11) exceeds rates typically cited in general manufacturing.[4,20]

The significant longitudinal threshold shift ($p < 0.001$) confirms that current mitigation strategies are insufficient for this demographic.

A critical finding is the instability of the "Warning" classification (HSE Category 2). Rather than serving as a stable plateau, it was a transitional phase toward severe impairment; 70% (n=7) of workers in this category migrated to Category 3 by 2025. This "diagnostic migration" indicates that the standard two-year surveillance interval is inadequate for detecting damage before clinical referral is required. [16]

The disparity between groups was absolute, with Group A (Gardeners) showing progression to the referral category in all workers (5/5, 100%). The dominance of Sub-category 3A (Rapid High-Frequency Loss) in Group A suggests exposure to high-intensity impulsive sound from landscaping machinery. Such noise carries a higher risk than continuous noise of equivalent energy,[21,22] leading to acute acoustic trauma rather than gradual decline.[15]

While noise is the primary driver,[18] individual factors likely play a synergistic role. Although the sample size limited statistical power, the clustering of smoking (60% in Group A) and hypertension (40% in Group A) suggests a potential "triad of risk" involving noise exposure, smoking-induced hypoxia, and metabolic stress. Smoking-induced hypoxia and vascular constriction may increase cochlear vulnerability and impair recovery from acoustic trauma. [9,11,23,24] Additionally, chemical contaminants in fuel exhaust may play a potentiating role.[25]

Finally, the effectiveness of Personal Protective Equipment (PPE) is called into question. Similar observations have been reported in other occupational settings, where inconsistent use of hearing protection devices has been associated with increased prevalence of hearing threshold impairment among noise-exposed workers.[26]

Real-world attenuation of earplugs is often lower than laboratory ratings due to poor fitting or inconsistent use.[27,28] The 100% referral rate in Group A may suggest potential limitations in PPE effectiveness or compliance; however, PPE use was not directly measured in this study.[28] These findings highlight the need for larger, prospective municipal surveillance studies.

Therefore, several limitations should be considered when interpreting the findings. First, the final analytical sample was relatively small (n = 23), limiting statistical power and the ability to perform multivariable analyses. Second, participant attrition was substantial, with approximately half of the initially identified cohort (44 workers) lacking complete paired audiometric data. Although attrition was largely administrative, selection bias cannot be fully excluded.

Third, potential confounding factors may have contributed to the observed differences in progression, including variability in baseline hearing status, non-occupational noise exposure, and consistency of hearing protection use. Finally, the observational design prevented causal inference. Larger prospective studies with improved retention and standardized exposure assessment are warranted.

Conclusion

This pilot longitudinal cohort study provides compelling evidence that municipal workers classified in Group A (gardeners) experience accelerated noise-induced hearing loss (NIHL) compared with their counterparts in Group B (drivers). The observation that 100% of Group A workers required clinical referral by 2025 highlights a critical limitation of the current preventive framework for this occupational subgroup and suggests a pattern of rapid progression associated with repeated exposure to high-intensity impulsive noise.[20]

Furthermore, the findings indicate that, for high-risk occupational groups, the "warning" classification (HSE Category 2) may represent a transitional stage rather than a stable condition, frequently progressing to more severe auditory impairment within the standard two-year surveillance interval.[16,27] The clustering of

synergistic risk factors—particularly smoking and hypertension—among the most affected workers further suggests that metabolic and vascular conditions may exacerbate cochlear susceptibility to acoustic trauma and accelerate the progression of hearing damage.[9,22]

These observations highlight the need for targeted preventive interventions structured according to the hierarchy of controls. First, priority should be given to reducing noise exposure at the source through engineering interventions. The implementation of a "Buy Quiet" procurement strategy is strongly recommended, whereby gasoline-powered gardening equipment is progressively replaced with professional-grade electric alternatives as existing machinery reaches the end of its operational lifespan. Such a substitution could substantially reduce exposure to impulsive noise and mechanical vibration associated with landscaping equipment.[20]

Second, administrative controls should be implemented to limit cumulative daily noise exposure. Job rotation strategies may reduce the prolonged operation of high-noise machinery by the same workers, allowing alternating assignments between noisy tasks (such as leaf blowing or mechanical trimming) and quieter activities, including manual planting or general maintenance.

In addition, improvements in hearing protection practices are warranted. Although personal protective equipment represents the final line of defense within the hierarchy of controls, it remains essential in high-noise environments. Mandatory individual fit testing should therefore be introduced to ensure proper acoustic sealing of earplugs and to verify effective attenuation under real-world working conditions. For tasks exceeding 95 dB(A), the implementation of dual hearing protection (earplugs combined with earmuffs) should be recommended until engineering controls successfully reduce exposure levels.[26,29]

Finally, enhanced health surveillance is necessary to evaluate the effectiveness of these preventive interventions. Given the rapid deterioration observed in this cohort, shortening the audiometric surveillance interval from the current 24 months to six months for high-risk workers could facilitate earlier detection of temporary threshold shifts and enable timely preventive intervention before permanent hearing impairment occurs.[13,30]

Acknowledgements

This research is not financially supported by any institution. The authors would like to thank all participants and colleagues who provided valuable feedback during the preparation of this research.

References

1. Papastergiou S, Karaiskos C, Damikouka I, Douna E, Koupidis S, Dounias G. Noise-induced hearing loss among Greek solid waste landfill workers. European Scientific Journal. 2025;21(37):30. Available from: https://doi.org/10.19044/esj.2025.v21n37p30
2. National Institute for Occupational Safety and Health. Criteria for a recommended standard: Occupational noise exposure. 1998. NIOSH publication no. 98-126. Available from: https://www.cdc.gov/niosh/docs/98-126/
3. Themann CL, Masterson EA. Occupational noise exposure: A review of its effects, epidemiology, and impact with recommendations for reducing its burden. J Acoust Soc Am. 2019;146(5):3879-3905. Available from: https://doi.org/10.1121/1.5134465
4. Masterson EA, Tak S, Themann CL, Wall DK, Groenewold MR, Deddens JA, et al. Prevalence of hearing loss in the United States by industry. American Journal of Industrial Medicine. 2013;56(6):670–81. Available from: https://doi.org/10.1002/ajim.22082

5. Coles RRA, Lutman ME, Buffin JT. Guidelines on the diagnosis of noise-induced hearing loss for medicolegal purposes. Clinical Otolaryngology 2000;25(4):264–73. Available from: https://doi.org/10.1046/j.1365-2273.2000.00368.x

6. Rabinowitz PM. Noise-induced hearing loss. American Family Physician. 2000;61(9):2749-56. Available from: https://www.aafp.org/pubs/afp/issues/2000/0501/p2749.html

7. Karaiskos CA, Rachiotis G, Simou E, Dounias G. Impact of subclinical hearing loss on quality of life among industrial workers. Cureus. 2025;17(7):e87575. Available from: https://doi.org/10.7759/cureus.87575

8. Fonte A, Ribeiro M. Environmental noise and annoyance in the urban area of Bragança, Portugal. Journal of Toxicology and Environmental Health Part A. 2023;86(1):1–14. Available from:

9. Ni CH, Chen ZY, Zhou Y, Zhou JW, Pan JJ, Liu N, et al. Associations of blood pressure and arterial compliance with occupational noise exposure in female workers of textile mill. Chinese Medical Journal. 2007;120(15):1309–13. Available from: http://pubmed.ncbi.nlm.nih.gov/17711734/

10. Basner M, Babisch W, Davis A, Brink M, Clark C, Janssen S, et al. Auditory and non-auditory effects of noise on health. The Lancet. 2014;383(9925):1325–32. Available from: https://doi.org/10.1016/S0140-6736(13)61613-X

11. Chang TY, Su TC, Lin SY, Jain RM, Chan CC. Effects of occupational noise exposure on 24-hour ambulatory vascular properties in male workers. Environmental Health Perspectives. 2007;115(11):1660–4. Available from: https://pmc.ncbi.nlm.nih.gov/articles/PMC2072860/

12. World Health Organization. Occupational noise: Assessing the burden of disease from work-related hearing impairment at national and local levels. 2004. Available from: https://www.who.int/publications/i/item/9241591927

13. Health and Safety Executive. Controlling noise at work: The Control of Noise at Work Regulations 2005 (Guidance on regulations L108). 3rd ed. Bootle: HSE Books; 2021. Available from: https://www.hse.gov.uk/pubns/books/l108.htm

14. European Parliament and the Council of the European Union. Directive 2003/10/EC of the European Parliament and of the Council of 6 February 2003 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (noise). Off J Eur Union. 2003 Feb 15;L42:38-44. Available from: https://osha.europa.eu/en/legislation/directives/82

15. Dobie RA. The burdens of age-related and occupational noise-induced hearing loss in the United States. Ear and Hearing. 2008;29(4):565–77. Available from: https://doi.org/10.1097/AUD.0b013e31817349ec

16. Kirchner DB, Evenson E, Dobie RA, Rabinowitz P, Crawford J, Kopke R, et al. Occupational noise-induced hearing loss. Journal of Occupational and Environmental Medicine. 2012;54(1):106–8. Available from: https://doi.org/10.1097/JOM.0b013e318242677d

17. Lie A, Skogstad M, Johannessen HA, Tynes T, Mahlum IS, Nordby KC, et al. Occupational noise exposure and hearing: A systematic review. International Archives of Occupational and Environmental Health. 2016;89(3):351–72. Available from: https://doi.org/10.1007/s00420-015-1083-5

18. Sliwinska-Kowalska M, Davis A. Noise-induced hearing loss. Noise & Health. 2012;14(61):274–80. Available from: https://doi.org/10.4103/1463-1741.104893

19. Patel J, Ghosh T. Assessment of noise-induced hearing loss among weaving factory workers in West Bengal, India. Int J Occup Saf Health. 2023;13(1):69-77. Available from: https://doi.org/10.3126/ijosh.v13i1.42281

20. Palmer KT, Griffin MJ, Syddall HE, Pannett B, Coggon D. Occupational exposure to noise and

the attributable burden of hearing difficulties in Great Britain. Occupational and Environmental Medicine. 2002;59(9):634–9. Available from: https://doi.org/10.1136/oem.59.9.634

21. Starck J, Toppila E, Pyykkö I. Impulse noise and risk criteria. Noise & Health 2003;5(20);63–73. Available from: https://pubmed.ncbi.nlm.nih.gov/14558894/

22. Le Prell CG, Yamashita D, Minami SB, Yamasoba T, Miller JM. Mechanisms of noise-induced hearing loss indicate multiple methods of prevention. Hearing Research. 2007;226(1–2):22–43. Available from: https://doi.org/10.1016/j.heares.2006.10.006

23. Mizoue T, Miyamoto T, Shimizu T. Combined effect of smoking and occupational exposure to noise on hearing loss in steel factory workers. Occupational and Environmental Medicine. 2003;60(1):56–9. Available from: https://doi.org/10.1136/oem.60.1.56

24. Pouryaghoub G, Mehrdad R, Mohammadi S. Interaction of smoking and occupational noise exposure on hearing loss: a cross sectional study. BMC Public Health. 2007;7:137. Available from: https://doi.org/10.1186/1471-2458-7-137

25. Mohammadi S, Mazhari MM, Mehrparvar AH, Attarchi MS. Effect of simultaneous exposure to occupational noise and cigarette smoke on binaural hearing impairment. Noise & Health. 2010;12(48):187–90. Available from: https://pubmed.ncbi.nlm.nih.gov/20603575/

26. Widuri A, Estigroho E, Pujiyanto E. Hearing threshold levels among clothes convection industry workers in Klaten, Central Java, Indonesia. Int J Occup Saf Health. 2024;14(3):345-51. Available from: https://doi.org/10.3126/ijosh.v14i3.59403

27. Fechter LD. Promotion of noise-induced hearing loss by chemical contaminants. Journal of Toxicology and Environmental Health Part A. 2004;67(8–10):727–40. Available from: https://doi.org/10.1080/15287390490428296

28. Arezes PM, Miguel AS. Hearing protection use in industry: The role of risk perception. Safety Science. 2005;43(4):253–67. Available from: https://doi.org/10.1016/j.ssci.2005.07.002

29. Tak S, Davis RR, Calvert GM. Exposure to hazardous workplace noise and use of hearing protection devices among US workers. American Journal of Industrial Medicine. 2009;52(5):358–71. Available from: https://doi.org/10.1002/ajim.20690

30. Verbeek JH, Kateman E, Morata TC, Dreschler WA, Mischke C. Interventions to prevent occupational noise-induced hearing loss. Cochrane Database of Systematic Reviews. 2012. Available from: https://doi.org/10.1002/14651858.CD006396.pub3

International Journal of Occupational Safety and Health

ISSN: 2091-0878 (Online) ISSN: 2738-9707 (Print)

Original Article

Lower-back discomfort and ergonomic hazards among artisanal fishermen in Tamil Nadu, India: a cross-sectional study

Adithiyalakshmi S[1], Sridevi Sivakami PL[2],

[1,2]Department of Food Service Management and Dietetics, School of Home Science, Avinashilingam Institute for Home Science and Higher Education for Women, Coimbatore, Tamil Nadu, India.

Corresponding author:
Srinivasa Narayanan Adithiyalakshmi,
Research Scholar,
Department of Food Service Management and Dietetics, School of Home Science, Avinashilingam Institute for Home Science and Higher Education for Women, Coimbatore, Tamil Nadu, India.
E-mail: adithiyaphdresources@gmail.com
ORCID ID: https://orcid.org/0009-0003-6656-2436

Date of submission: 31.05.2025
Date of acceptance: 22.02.2026
Date of publication: 15.04.2026

Conflicts of interest: None
Supporting agencies: The Indian Council for Social Science Research – Centrally Administered Full-term Doctoral Fellowship (2024 – 2025) and the Dr. T.S Avinashilingam Fellowship (2023-2024), Avinashilingam Institute for Home Science and Higher Education for Women, Coimbatore, Tamil Nadu, India.
DOI:https://doi.org/10.3126/ijosh.v16i1.79507

Copyright: This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License

ABSTRACT

Introduction: Lower back discomfort is a prevalent occupational health issue among fishermen, substantially contributing to disability adjusted life years and reduced work performance. The primary aim of the study is to examine the lower back discomfort, occupational profile, ergonomic hazard exposure and overall health and wellbeing among artisanal fishermen.

Methods: The present study has been conducted among 400 randomly selected artisanal fishermen from coastal villages of Ramanathapuram District, Tamil Nadu, India between February 2024 and April 2025. Data has been collected using a pretested interview schedule, the standardized Nordic Musculoskeletal Questionnaire (2007), Perceive Stress Scale – 10 and adapted Workplace health and safety survey. Descriptive statistics, Spearmen correlation and regression have also been performed.

Results: Among the selected 400 artisanal fishermen, 269 (67.3%) reported lower back discomfort in the past 12 months with 68 (22%) have experienced interference in daily activities. Ergonomic hazards including lifting of heavy weights 172 (64%), repetitive movements 252 (91%), improper working postures 78 (29%) and prolonged standing (>2 hours) 105 (39%) have been significantly associated with Lower Back Discomfort. With frequent lifting showing adjusted odds ratios of 7.7 (always) and 6.4 (often), psychosocial factors such as poor sleep quality (aOR = 3.6), moderate perceived stress (aOR = 2) and alcohol consumption (22%, $p<0.05$) have also showed significant associations with Lower Back Discomfort. No significant relationships have been observed with demographics, body mass index and comorbidities. The coping strategies have included medication use (70%) and medical consultation (20%).

Conclusion: The study highlights that ergonomic hazards and psychosocial stressors are key determinants of lower back discomfort among artisanal fishermen. Tailored ergonomic interventions, occupational health education and stress management strategies are essential to mitigate musculoskeletal strain to improve their Quality of Life.

Keywords: Alcohol consumption, Artisanal Fishermen, Ergonomic Hazards, Lower back discomfort, Psychosocial stress

Introduction

Work-related musculoskeletal disorders or discomfort encompass a range of conditions affecting muscles, bones, joints, nerves, and other related tissues that arise from or are aggravated by occupational ergonomic exposures. Although these pains are non-fatal, they significantly contribute to disability. Globally, musculoskeletal pain accounts for about 150 million disability adjusted life years, with low back pain alone responsible for around 64 million disabilities adjusted life years.[1]

Small-scale artisanal fishermen are classified under ISCO Unit Group 6-41 (Subsistence fishers, hunters and gatherers), which includes individuals engaged in traditional, non-industrial fishing using manual or small-scale methods.[2] The fisheries sector plays a vital role in achieving Sustainable Development Goals 1, 2, and 3 by supporting food security, nutrition, and livelihoods. However, it is also associated with significant occupational risks that impact public health. According to the International Labor Organization, the fishing industry records one of the highest workplace mortality rates, with an estimated 120 million accidents and 200,000 fatalities annually.[3] Fishers face a range of distinct challenges as they are exposed to harsh environmental conditions, physical hazards and poor working environments.[4]

Musculoskeletal disorders result from a mismatch between work demands and the worker's functional capacity. Ergonomics seeks to minimize this mismatch by designing tasks, tools, and environments that align with individuals' physiological and psychological capabilities.[5] Failure in incorporating these principles often results in physical strain caused by ergonomic hazards among fishers, which elevates the likelihood of musculoskeletal disorders.[6]

The Indian Ocean has long been a vital source of nutrition and livelihood; however, fishermen continue to experience low social status and adverse living conditions, and limited research has highlighted the occupational hazards and health issues they face.[7,8] Occupational health of artisanal fishermen is influenced by both fatal and non-fatal injuries, ranging from musculoskeletal disorders to dermatological and sensory impairments in developing countries.[9] Many cross-sectional studies and systematic reviews,[10] show the higher prevalence of lower back discomfort among artisanal fishers in India,[11] Brazil,[12] Srilanka,[13] Denmark,[14] and other countries.

Low back pain is the most prevalent occupational health issue among fishermen, reducing their work capacity and quality of life. In 2020, it affected about 619 million people globally and is projected to rise to 843 million by 2050, of which 38.8 percent of disability adjusted life years are linked with occupational factors, smoking, and high body mass index.[15] The development of work-related musculoskeletal low back pain is multifactorial, involving ergonomic, biomechanical, functional, and psychosocial components. Sustained mechanical loading and poor postures often cause paravertebral muscle injury and pain, increasing the risk of chronic low back discomfort.[16,17]

Although several studies investigate musculoskeletal lower back discomfort and its ergonomic risk factors, only a few have been conducted among artisanal fishermen in the south coast district of Tamil Nadu. The primary aim of this study is to examine the association between lower back discomfort, occupational profile, ergonomic hazard exposure, health, and well-being among the selected artisanal fishermen in Ramanathapuram District of Tamil Nadu, India.

Methods

This cross-sectional study investigated the occupational profile, ergonomic hazard exposure, and prevalence of musculoskeletal low back pain among the selected artisanal fishermen (n=400) in Ramanathapuram District of Tamil Nadu, India. For simple random sampling, the sample

size is calculated using the Yamane et al. (1967) formula.[18]

Sample size formula (n) = N / 1 + N*(e²)

The total number of fisherfolk in Ramanathapuram District: 1,88,915

The total number of fishermen in Ramanathapuram District: 66,884

(Marine Fisheries census, 2016)

According to Yamane et al (1967),

N : Population size
e : Margin error (5% - 0.05)
(n) = N / 1 + N*(e²) = 66,884 / 1+ 66,884*(0.05)²
Sample size (n) = 400

The inclusion criteria is

- Male artisanal fishermen aged between 18 – 60 years in Ramanathapuram District of Tamil Nadu.
- Actively engaged in fishing for more than one year.

Exclusion criteria

- The fisherman with pre-existing spinal injuries, chronic illness unrelated to occupation and
- Those unwilling to participate.

About 420 - 430 fishermen have been interviewed; incomplete and missing data are excluded from analysis resulting in a final sample of 400 participants for analysis.

The study has been approved by the Institutional Human Ethical Committee of Avinashilingam Institute for Home Science and Higher Education for Women, Coimbatore, Tamil Nadu, India (Approval number: AUW/XMT-038, FSMD/IHEC/23–24). Before the interview, the researcher explained the purpose of the study, and informed consent was obtained from all participants prior to data collection. The study has been conducted in accordance with the principles of the Declaration of Helsinki. The interview has been conducted in face-to-face mode, held for about 25 to 30 minutes. The interview schedule for the study has been formulated and validated for the collection of data. The data collection has been carried from February 2024 to April 2025 in fifteen coastal villages (Devipattinam, Rameshwaram, Mandapam, Pamban, Pudumadam, Muthupettai, Kuthukkalvalsai, Thondi, Tiruppalaikudi, Kadaladi, Alagankulam, Sethukarai, Keelakarai, Ervadi and Valinokkam) of Ramanathapuram District of Tamil Nadu, India.

The occupational profile of the interview schedule has investigated the variables such as age, occupational structure, nature of fishing, number of hours spent fishing, and experience of selected artisanal fishermen. The standardized and self-reported Nordic Musculoskeletal Questionnaire (2007),[19] and Perceived Stress Scale – 10,[20] is used for the assessment of low back discomfort and stress respectively, the Nordic musculoskeletal questionnaire assesses the musculoskeletal discomfort across different body parts, however, the present study specifically focuses on lower back discomfort experienced over the 12 months and the previous seven days, its impact on daily activities and he use of medications and medical treatments.

Ergonomic hazard exposure is an adapted tool from the Workplace Health and Safety Survey by the Institute for Work and Health.[21] It has eight questions investigating the frequency of exposure to lifting heavy items (>20kgs), repetitive movements at work, involved in unfamiliar tasks, interaction with hazardous substances such as chemicals and explosives, improper working postures, work at two meters above ground level, high noise pollution and standing more than two hours at stretch during work at a scale of one to four (1-Rarely to 4-Always). The prevalence of diseases such as diabetes, hypertension, comorbidity, quality of sleep (disrupted sleep: waking frequently during sleep; difficulty in sleep: difficulty in initiating sleep as well as maintaining continuous sleep for at least 6-7 hours), and addictive behavior is

collected through direct interviews with selected artisanal fishermen.

The Perceived Stress Scale – 10, with 10 questions assessing stress experienced over the past seven days, has been investigated. The presence or absence of lower back discomfort is treated as the dependent variable, with occupational profile, ergonomic hazard exposure, substance use, presence of non-communicable diseases, comorbidity, quality of sleep, and perceived stress being the independent variables. The chi-square analysis, Spearman correlation, and binomial regression with model fit are evaluated by the Hosmer and Lemeshow test ($p>0.05$) at 95% statistical significance using Statistical Package for Social Sciences version 21.

Descriptive statistics are presented within each group. Fishermen with lower back discomfort are tested using chi-square analysis (total sample n=400) with a dichotomous variable (1=presence of lower back discomfort, 0 = absence of lower back discomfort). Logistic regression analysis is used to examine associated factors; logistic regression coefficients (B) represent log-odds; adjusted odds ratios (AORs) are obtained by exponentiating B, with 95 percent confidence intervals.

Results

The present study has involved in the investigation of ergonomical hazard exposure and its impact on musculoskeletal low back discomfort among selected artisanal fishermen (n=400). Consistent with findings from previous studies, a considerable proportion of the selected fishermen (269; 67.3%) reported experiencing low back discomfort over the past 12 months. Among 269 selected artisanal fishermen, about 224 selected artisanal fishermen experienced low back discomfort during the past seven days, and it disturbed their day-to-day work and interfered with their ability to work (n=68).

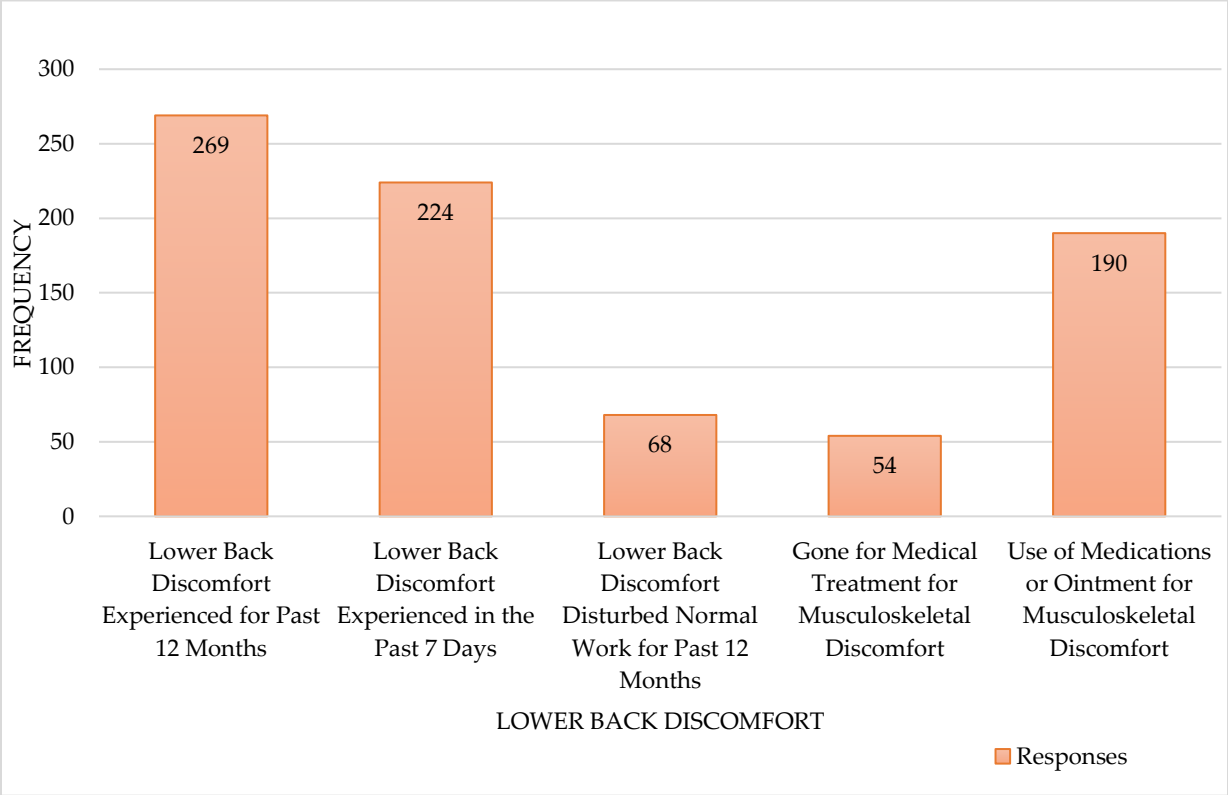


Figure 1: Prevalence of Lower Back Musculoskeletal Discomfort among Selected Artisanal Fishermen

Table 1: Association between the Presence of Lower Back Discomfort and the Occupational Profile of Selected Artisanal Fishermen

Background Information		Lower Back Discomfort Experienced by Selected Artisanal Fishermen (n=269) n(%)	Artisanal Fishermen without Lower Back Discomfort (n=131) n(%)	p value
Age (Years)	Below 24	14(5)	4(3)	0.666
	25-35	28(10)	19(15)	
	36-45	83(31)	37(28)	
	46-55	80(30)	40(31)	
	Above 56 (≤ 60)	64(24)	31(24)	
Occupational Structure	Self-employed (Own Vessel)	137(51)	77(59)	0.261
	Regular wages	132(49)	53(41)	
Socioeconomic Status	Upper class	0	0	0. 902
	Upper middle class	37(9)	24(18)	
	Middle class	307 (77)	94(72)	
	Lower middle class	56 (14)	13(10)	
	Lower class	0	0	
Nature of fishing	Shallow sea fishermen + Net knitting	190(71)	102(78)	0.308
	Deep-sea fishermen + Net knitting	70(26)	26(20)	
	Both	9(3)	3(2)	
Number of hours spent fishing	Below 8	182(68)	95(73)	0.323
	Above 8	87(32)	36(27)	
Experience in fishing (Years)	One to five	8(3)	3(2)	0.465
	Six to ten	24(9)	8(6)	
	Eleven to Fifteen	57(21)	29(22)	
	Sixteen to Twenty	108(40)	45(34)	
	Twenty-one years and above	72(27)	46(35)	

Percentages are calculated column-wise based on the presence or absence of lower back discomfort

Table 1 shows that across all variables of the occupational profile, including age, occupational structure, socioeconomic status, working hours, and experience, there is no significant association with lower back discomfort.

Furthermore, the association between lower back discomfort and the frequency of ergonomic hazard exposure is analyzed. Repetitive movements 252 (94%), lifting heavy items 172 (64%), and standing for more than two hours 105 (39%) are frequently experienced, and this is statistically significant.

Table 2: Occupational Ergonomic Hazard Exposure and Presence of Lower Back Discomfort among Selected Artisanal Fishermen

Ergonomic Hazards	Lower Back Discomfort Experienced by Selected Artisanal Fishermen n(%)				p value
	Always	Often	Sometimes	Never	
Lift, carry, or push items heavier than 20kg at least 10 times a day	172(64)	92(34)	2(1)	3(1)	0.007*
Repetitive movements of the body during work	252(94)	13(5)	1(0.4)	3(1)	0.016*
Unfamiliar tasks	2(0.7)	3(1)	30(11)	234(87)	0.947
Interact with hazardous substances	0	63(23)	135(50)	71(26)	0.755
Bent, twisted or improper position at work	79(29)	114(42)	74(278)	2(0.7)	0.044*
Working at a height of 2 meters or above the ground level	3(1)	29(11)	105(39)	132(49)	0.426
Working in high noise pollution	2(1)	10(4)	15(6)	242 (90)	0.545
Standing for more than 2 hours during work	105(39)	154(57)	4(2)	6(2)	0.004**

*p value<0.05, **p value<0.01.

Table 3: Stratification of Health and Well-being based on the Presence of Lower Back Discomfort among Selected Artisanal Fishermen

Health Profile		Lower Back Discomfort Experienced by Selected Artisanal Fishermen (n=269) n(%)	Artisanal Fishermen without Lower Back Discomfort (n=131) n(%)	p value
Body Mass Index	Underweight (<18.5kg/m^2)	14 (5)	9(7)	0.827
	Normal (18.5 -24.9kg/m^2)	114 (42)	53(41)	
	Overweight (>24.9kg/m^2)	141 (52)	69(53)	
Smoking	Yes	61(23)	29(22)	0.904
	No	208(77)	102(78)	
Alcohol Consumption	Yes	60(22)	17(13)	0.026*
	No	209(78)	114(87)	
Diabetes Mellitus	Yes	93(35)	38(29)	0.255
	No	175(65)	93(71)	
Hypertension	Yes	93(35)	42(32)	0.295
	No	175(65)	89(68)	
Comorbidity	Yes	71(26)	26(20)	0.152
	No	198(74)	105(80)	
Perceived Stress	Low	8(3)	14(11)	0.002**
	Moderate	261(97)	117(89)	
Quality of Sleep	Good	169(63)	96(73)	0.043*
	Disrupted	88(33)	26(20)	
	Difficulty in sleep	12(5)	9(7)	

*pvalue<0.05, **pvalue<0.01. Percentages are calculated column-wise based on the presence or absence of lower back discomfort

About 60(22%) of the artisanal fishermen with lower back discomfort have reported both smoking and alcohol consumption, and a significant association has been observed between alcohol consumption and lower back discomfort (Table 3).

The prevalence of morbidities and comorbidities (20 – 35%) did not show a significant distribution with lower back discomfort. However, LBD is found to affect both the quality of sleep and the perception of stress among the selected artisanal fishermen. Further correlation and regression analysis have confirmed a positive relationship between ergonomic hazard exposure and experience of low back discomfort and stress.

Table 4: Correlation Analysis between Ergonomic Hazard Exposure and Other Variables

Variables	Age (Years)	Working hours	Perceived Stress	Quality of Sleep	Overall Ergonomic Hazard Exposure	Lower back discomfort
Age (Years)	1					
Working hours	0.636	1				
Perceived Stress	0.212	0.403	1			
Quality of Sleep	0.253	0.619	0.704	1		
Overall Ergonomic Hazard Exposure	0.269	0.349	0.004**	0.132	1	
Lower back discomfort	0.983	0.324	0.001**	0.075	0.334	1

*p-value<0.05, **p-value<0.01.

Table 5: Logistic Regression of Ergonomic Hazard Exposure with Lower Back Discomfort

Variables	Category	Lower Back Discomfort			
		B	aOR	CI	p value
Age (Years)	Below 24	0.69	1.99	0.54 – 7.37	0.30
	25-35	-0.42	0.66	0.3 – 1.44	0.29
	36-45	-0.10	0.90	0.48 – 1.68	0.75
	45-55	-0.14	0.87	0.47 – 1.61	0.66
	Above 56 (≤ 60)	RC			
Working Hours	Below 8	-0.21	0.811	0.49 – 1.324	0.40
	Above 8	RC			
Socio economic Status	Upper middle class	RC			
	Middle class	0.11	1.11	0.43 – 2.85	0.825
	Lower middle class	0.54	1.71	0.91 – 3.2	0.096
Lift, carry or push items heavier than 20kg at least 10 times a day	Always	2.04	7.77	2.2 – 26.4	0.001*
	Often	1.9	6.4	1.93 – 21.12	0.002*
	Sometimes + Never	RC			
Bent, twisted or improper position at work	Always	0.055	1.056	0.61 – 1.82	0.66
	Often	0.26	1.3	0.64 – 2.61	0.45
	Sometimes + Never	RC			
Stand more than 2 hours during work	Always	-0.41	0.66	0.22 – 1.99	0.46
	Often	-0.37	0.69	0.22 – 2.15	0.5
	Sometimes + Never	RC			
Perceived Stress	Low	RC			
	Moderate	1.27	3.57	1.28 – 9.89	0.014*
Quality of Sleep	Good	RC			
	Disrupted	0.73	2.06	1.21 – 3.52	0.008
	Difficulty in sleep	-0.43	0.65	0.25 – 1.66	0.65

*p-value<0.05, **p-value<0.01. RC – Reference category; B – logistic regression coefficients (log odds); AOR – adjusted Odds Ratio.

The negative B values indicate reduced odds of lower back discomfort compared with the reference category.

A binary logistic regression model is employed, and its fit is assessed using the Hosmer-Lemeshow test. As shown in Table 5, ergonomic hazards (lift/ carry/ push items heavier than 20kgs/ per day) are the predominant cause of lower back discomfort and it also significantly impacts stress and sleep.

Discussion

The National Institute for Occupational Safety and Health (NIOSH) has defined work-related musculoskeletal disorders as conditions in which the musculoskeletal system is worsened by ergonomic hazards. In the present study, the 12-month prevalence of lower back discomfort among the selected artisanal fishermen was 269 (67.3%), of whom 68 (22%) reported that it interfered with their daily activities. Exposure to occupational ergonomic hazards is the predominant cause of any musculoskeletal discomfort. Artisanal fishermen typically perform physically demanding tasks such as steering vessels, operating navigational tools, deploying and retrieving fishing gear like nets and traps, and frequently transferring heavy loads of 15 to 20kg.[11] In the study, significant associations are observed between lower back discomfort and specific ergonomic hazards such as lifting heavy loads (64%, $p<0.01$), retrieving wetted nets with fish, lifting of fish crates, and hauling anchors, which often demand high physiological workload.[22] In addition, low intensity frequent movements (91%,$p<0.05$) like net repairing and knitting of nets, unloading and sorting of fishes coupled with improper or twisted working postures (29%, $p<0.05$) such as bending, crouching, leaning forward and standing for more than two hours (39%, $p<0.01$) puts excessive strain on the lower back muscles as they often work in confined spaces limiting movements, forcing into awkward postures contributing to prolonged muscle contraction and biomechanical stress.[23] While earlier studies among Fishermen in Vietnam predominantly have highlighted the injuries over the upper extremities, followed by lower limbs, with head and systemic injuries being relatively less frequent. [24] Similarly, a study among informal fish vendors in Sri Lanka has also highlighted the influence of lifting and carrying of heavy loads on wrist musculoskeletal discomforts.[25]

Binary logistic regression has supported these findings through the Hosmer and Lemeshow test, yielding a p-value greater than 0.05, indicating good model fit. Fishermen frequently exposed to ergonomic hazards have had higher odds of experiencing lower back discomfort. Specifically, frequent exposure to lifting heavy loads has been associated with adjusted odds ratios of 7.7 and 6.4 for those reporting the activity 'always' and 'often', respectively. This underscores that each additional unit of exposure to heavy lifting is associated with a corresponding increase in the likelihood of lower back discomfort.

Psychosocial factors have been shown to significantly influence lower back discomfort. Poor sleep quality ($p<0.01$) and moderate perceived stress (97%, $p<0.01$) are significantly associated, with adjusted odds ratios of 3.6 and 2; underscoring the impact of poor-quality sleep and stress on musculoskeletal pain. Fishermen with lower back discomfort have reported significantly higher perceived stress and a greater proportion experiencing disrupted sleep. These findings are consistent with previous studies, which have shown that mental health issues, poor sleep and stress are cofactors, affecting over half of the fishermen and contributing to the development of musculoskeletal discomforts. [6,26,27,28]

Alcohol consumption (22%,$p<0.05$) has shown a significant association with lower back discomfort; substance usage is reportedly higher among fishermen with lower back discomfort, often adopted as a coping mechanism, which may exacerbate physical health issues.[29,30] Conversely, no significant association has been found between body mass index or comorbid conditions such as diabetes mellitus and

hypertension with lower back discomfort which aligns with similar findings in the literature.[23,31]

Most of the fishermen with lower back discomfort 213(79%) in the present study belong to the middle socioeconomic class, often owning their fishing vessel and receiving regular wages. Notably, working hours are not associated with lower back discomfort; this may be attributed to the seasonal and variable nature of artisanal fishing schedules that are frequently adjusted based on marine ecosystems, fish availability, potentially acting as a confounding factor.[32]

The prevalence and patterns observed are consistent with studies from Brazil, reporting high lower back discomfort among fishers engaged in direct fishing activities,[22] while a study on industrial fishermen also reported even higher prevalence of lower back discomfort (92%).[11] However, the findings of the present study show an insignificant association with demographic and occupational profile, which contradicts a review highlighting that age, duration of occupation, type of fishing, and gear used are linked with low back pain.[8] In line with findings from Nigeria[17], where middle-aged artisanal fishermen have shown a higher prevalence of lower back discomfort, although the association has been insignificant. This aligns with a Korean study where age did not significantly predict musculoskeletal discomfort.[26] A North Carolina cohort study suggested higher rates of lower back discomfort among younger or less experienced fishermen.[16] Similarly, a report from Egypt had also suggested a higher prevalence of lower back discomfort among younger fishermen.[33] These inconsistencies may be due to methodological variations and occupational differences.

Although previous studies linked lower income,[34] work-family imbalance, and job insecurity,[35] which may adversely impact fishermen's occupational functioning by reducing work capacity, leading to increased absenteeism and limited performance. These factors are not significant in the study, possibly due to divergent sample sizes, characteristics, occupational practices, and reporting behaviors.

Coping strategies among selected fishermen have included medications use (70%) and medical consultation (20%). The higher prevalence of self-medication suggests a need for improved access to occupational health services. Non-pharmacological interventions such as moderate to high intensity exercises for low back pain, trunk coordination, and strengthening exercises can be effective in managing lower back discomfort, in line with 2021 Academy of Orthopedic Physical Therapy guidelines, and should be tailored to the occupational demands of fishermen.[36,37] Preventive strategies, including task design, lifting aids, posture and handling training, sleep and stress interventions, are essential to mitigate the cumulative impact of ergonomic hazards and psychosocial stressors.

Despite several global studies on musculoskeletal discomfort among fishermen, few detailed investigations exist from south coastal India, particularly from Ramanathapuram, Tamil Nadu, which lies in the Exclusive Economic Zone. Further, the study offers relevant insights into the associations among multiple domains, drawing on several literature reviews and recommendations, along with evidence-based guidelines for understudied vulnerable populations.

Limitations

The cross-sectional study design limits causal inference; additional limitations include self-reported outcomes, lack of severity grading for lower back discomfort, and absence of clinical and radiological confirmation. Also, data collection spans the pre- and post-monsoon seasons, coinciding with variable fishing cycles that may have influenced the reported ergonomic exposures. Also, the analysis did not adjust for village level clustering, which could have led to minor underestimation of standard errors.

Conclusion

Artisanal fishermen are predominantly exposed to multiple ergonomic hazards and psychosocial stressors, which significantly increase the likelihood of lower back discomfort. A tailored ergonomic and psychosocial intervention focusing on lifting aids, posture training, stress, and sleep management is urgently needed to reduce musculoskeletal risk and improve the occupational health of artisanal fishermen.

Acknowledgements

The researcher sincerely acknowledges the Institutional Human Ethics Committee for approving the conduct of the study, the village heads of the coastal communities for granting permission to collect data, the participants for their cooperation and the reviewers for their constructive feedback.

Conflict of Interest

None

Funding

The present study is partially funded by the Indian Council for Social Science Research – Centrally Administered Full-term Doctoral Fellowship (2024 – 2025) and the Dr. T.S Avinashilingam Fellowship (2023-2024), Avinashilingam Institute for Home Science and Higher Education for Women, Coimbatore, Tamil Nadu, India.

References

1. Mishra S, Avinash G, Kundu MG, Verma J, Sheth A, Dutta A. Work-related musculoskeletal disorders among various occupational workers in India: a systematic review and meta-analysis. J Occup Health. 2025;67(1). Available from: https://doi.org/10.1093/joccuh/uiae077
2. International Labour Office. International Standard Classification of Occupations: ISCO-08. Revised edition. Geneva: International Labour Office. 2012. Available from: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://webapps.ilo.org/ilostat-files/ISCO/newdocs-08-2021/ISCO-08/ISCO-08%20EN%20Vol%201.pdf
3. Barrow A, Kongira A, Nget M, Sillah SO, Jatta SP, Badjie M, et al. Epidemiology of occupational hazards and injuries among fishermen at Tanji fishing site in The Gambia: an analytical cross-sectional study. Environ Health Insights. 2022;16:11786302221088699. Available from: https://doi.org/10.1177/11786302221088699
4. FAO/ILO/IMO. Safety and Working Conditions in the Fisheries Sector: Legal and Policy Avenues for Strengthened Decent Work Standards in the Fisheries Sector (JWG 5/INF.7). Rome: Food and Agriculture Organization of the United Nations; 2022. Available from: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://openknowledge.fao.org/server/api/core/bitstreams/12375e0e-abf2-493e-87fa-55d85201d526/content
5. Luttmann A, Jäger M, Griefahn B, Caffier G, Liebers F, van der Beek AJ. Preventing Musculoskeletal Disorders in the Workplace. Protecting Workers' Health Series No. 5. Geneva: World Health Organization; 2003. Available from: https://apps.who.int/iris/handle/10665/42651
6. Müller JD, da Silva EM, Franco Rego R. Prevalence of musculoskeletal disorders and self-reported pain in artisanal fishermen from a traditional community in Todos-os-Santos Bay, Bahia, Brazil. Int J Environ Res Public Health. 2022;19(2):908. Available from: https://doi.org/10.3390/ijerph19020908
7. Ratheesh M, Meharoof M, Albert CA. Sustainable Development Goals and fisheries sector: progressing towards a sustainable future. Int J Fish Aquat Stud. 2023;6:12–25. Available from: https://www.researchgate.net/publication/371718534
8. Rahaman SN, Samanta S, Banerjee J, Dash SK, Giri B, Das S, et al. Sociodemographic profile, nutritional and health status of fishermen: a review. Bangladesh J Med Sci. 2021;20(4):707–13. Available from: https://doi.org/10.3329/bjms.v20i4.54124

9. Shrestha S, Shrestha B, Bygvraa DA, Jensen OC. Risk assessment in artisanal fisheries in developing countries: a systematic review. Am J Prev Med. 2022;62(4):e255–e264. Available from: https://doi.org/10.1016/j.amepre.2021.08.031
10. Belz L, Fritze P, Harth V, Oldenburg M. A systematic review on the impact of ship movements on the lower back among maritime workers. Int Marit Health. 2024;75(3):155–66. Available from: https://doi.org/10.5603/imh.100136
11. Dabholkar TA, Nakhawa P, Yardi S. Common musculoskeletal problems experienced by fishing industry workers. Indian J Occup Environ Med. 2014;18(2):48–51. Available from: https://pubmed.ncbi.nlm.nih.gov/25568597/
12. Gotardelo MPS, Rodrigues ALM, Quaresma FRP, Pontes-Silva A, Maciel ES. Work-related musculoskeletal disorders in vulnerable populations: what are the most common body parts affected? BMC Public Health. 2023;23:1635. Available from: https://doi.org/10.1186/s12889-023-16570-2
13. Harshani SR, Abeysena C. Musculoskeletal symptoms, skin disorders and visual impairment among fishermen in Kalpitiya Division. Ceylon Med J. 2015;60(3):90–4. Available from: https://doi.org/10.4038/cmj.v60i3.8080
14. Østergaard H, Jepsen JR, Berg-Beckhoff G. The workload of fishermen: a cross-sectional survey among Danish commercial fishermen. Int Marit Health. 2016;67(2):97–103. Available from: https://doi.org/10.5603/IMH.2016.0019
15. GBD 2021 Low Back Pain Collaborators. Global, regional, and national burden of low back pain, 1990–2020, its attributable risk factors, and projections to 2050: a systematic analysis of the Global Burden of Disease Study 2021. Lancet Rheumatol. 2023;5(6):e316–e329. Available from: https://doi.org/10.1016/S2665-9913(23)00098-X
16. Kucera KL, Loomis D, Lipscomb HJ, Marshall SW, Mirka GA, Daniels JL. Ergonomic risk factors for low back pain in North Carolina crab pot and gill net commercial fishermen. Am J Ind Med. 2009;52(4):311–21. Available from: https://doi.org/10.1002/ajim.20676
17. Dienye PO, Birabi BN, Diete-Spiff KO, Dienye NP. The burden of low back pain among fishermen: a survey in a rural fishing settlement in Rivers State, Nigeria. Am J Mens Health. 2015;10(6):NP89–NP98. Available from: https://doi.org/10.1177/1557988315584375
18. Yamane T. Statistics: An Introductory Analysis. 2nd ed. New York: Harper and Row. 1967. Available from: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.gbv.de/dms/zbw/252560191.pdf
19. Crawford JO. The Nordic Musculoskeletal Questionnaire. Occup Med (Lond). 2007;57(4):300–1. Available from: https://doi.org/10.1093/occmed/kqm036
20. Cohen S, Kamarck T, Mermelstein R. A global measure of perceived stress. J Health Soc Behav. 1983;24(4):385–96. Available from: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.cmu.edu/dietrich/psychology/stress-immunity-disease-lab/scales/pdf/globalmeas83.pdf
21. Institute for Work & Health. OHS Vulnerability Measure. Toronto (ON): Institute for Work & Health. 2016. Available from: http://www.iwh.on.ca/ohs-vulnerability-measure
22. Souza ES, Figueiró MIR, Justo TS, Madeira K, Longen WC. Functional health and perceived exertion in artisanal fishermen working offshore. Rev Bras Med Trab. 2021;19(2):132–9. Available from: http://dx.doi.org/10.47626/1679-4435-2020-523
23. Thamrin Y, Pasinringi S, Darwis AM, Putra IS. Relation of body mass index and work posture to musculoskeletal disorders among fishermen. Gac Sanit. 2021;35(Suppl 1):S79–S82. Available from: https://doi.org/10.1016/j.gaceta.2020.12.022
24. Nguyen VT, Nguyen BN, Nguyen TS, Tran QC, Ho VH, Nguyen HH. Prevalence of Accidents and Injuries and Related Factors of Fishermen Fishing Offshore in the North of Vietnam. International Journal of Occupational Safety and Health. 2024;14(2):228–36. Available from: https://doi.org/10.3126/ijosh.v14i2.56367
25. Thariq MG, Safna FS, Nikzaad R. Ergonomic evaluation of work related musculoskeletal disorders in informal work: a study on fish

vendors in Ampara, Sri Lanka. Int J Occup Saf Health. 2025;15(2):242–50. Available from: https://doi.org/10.3126/ijosh.v15i2.64899

26. Lee J, Sim B, Ju B, Lee CG, Park KS, Kim MJ, et al. Population-attributable fraction of indicators for musculoskeletal diseases: a cross-sectional study of fishers in Korea. Ann Occup Environ Med. 2022;34:e23. Available from: https://doi.org/10.35371/aoem.2022.34.e23
27. Hu D, Zhang Y, Liu X, Yang X, Liang X, Hu X, et al. Sleeping <6.55 h per day was associated with a higher risk of low back pain in adults aged >50 years: a Korean nationwide cross-sectional study. Front Public Health. 2024;12:1429495. Available from: https://doi.org/10.3389/fpubh.2024.1429495
28. Laraqui O, Roland-Levy C, Manar N, Laraqui S, Ghailan T, Deschamps F, et al. Health status, sleeping habits and dyssomnia of coastal fishermen. Int Marit Health. 2022;73(4):163–71. Available from: https://doi.org/10.5603/IMH.2022.0029
29. Doza S, Bovbjerg VE, Vaughan A, Nahorniak JS, Case S, Kincl LD. Health-related exposures and conditions among US fishermen. J Agromedicine. 2022;27(3):284–91. Available from: https://doi.org/10.1080/1059924X.2021.1944416
30. Speir C, Ridings C, Marcum J, Drexler M, Norman K. Measuring health conditions and behaviours in fishing industry participants and fishing communities using the Behavioral Risk Factor Surveillance Survey (BRFSS). ICES J Mar Sci. 2020;77(5):1830-40. Available from: https://doi.org/10.1093/icesjms/fsaa032
31. Roseen EJ, Rajendran I, Stein P, Fredman L, Fink HA, LaValley MP, et al. Association of back pain with mortality: a systematic review and meta-analysis of cohort studies. J Gen Intern Med. 2021;36(10):3148–58. Available from: https://doi.org/10.1007/s11606-021-06732-6
32. Fitria S, Anggraini R, Nasution A, Zainuddin Z, Azhar A, Sudjatmoko F. Prevalence and risk factors of low back pain in fishermen in Bengkulu City: a cross-sectional study. J Kedokteran Raflesia. 2024;10(2):69–76. Available from: https://doi.org/10.33369/juke.v10i2.38974
33. Zytoon MA, Basahel AM. Occupational safety and health conditions aboard small and medium-size fishing vessels: differences among age groups. Int J Environ Res Public Health. 2017;14(3):229. Available from: https://doi.org/10.3390/ijerph14030229
34. Jazeela J. Impact of work and working conditions on low back pain among fisherwomen: a cross-sectional study in Trivandrum. Popul Med. 2023;5(Suppl):A1390. Available from: https://doi.org/10.18332/popmed/164925
35. Yang H, Haldeman S, Lu ML, Baker D. Low back pain prevalence and related workplace psychosocial risk factors: a study using data from the 2010 National Health Interview Survey. J Manipulative Physiol Ther. 2016;39(7):459–72.Available from: https://doi.org/10.1016/j.jmpt.2016.07.004
36. George SZ, Fritz JM, Silfies SP, Schneider MJ, Beneciuk JM, Lentz TA, et al. Interventions for the management of acute and chronic low back pain: revision. J Orthop Sports Phys Ther. 2021;51(11):CPG1–CPG60. Available from: https://doi.org/10.2519/jospt.2021.0304
37. Dunleavy K, Radunovich H, Beneciuk J, Hu B, Yang Y, Blythe J, et al. Self-management strategies for low back pain among horticulture workers: protocol for a type II hybrid effectiveness-implementation study. JMIR Res Protoc. 2025;14:e64817. Available from: https://doi.org/10.2196/64817

International Journal of Occupational Safety and Health

ISSN: 2091-0878 (Online) ISSN: 2738-9707 (Print)

Original Article

Prevalence of work-related musculoskeletal disorders and vision problems among electronics industry employees in Chennai, India

Sharon N[1], Saranya R[2], Naveen Shyam Sundar R[1]

[1]Department of Community Medicine, Shri Sathya Sai Medical College and Research Institute, Sri Balaji Vidyapeeth Deemed to Be University, Puducherry, India
[2]Department of Community Medicine, Madha Medical College and Research Institute, Chennai, India

Corresponding author:

Sharon Nelson,
Assistant Professor, Department of Community Medicine, Shri Sathya Sai Medical College and Research Institute, Sri Balaji Vidyapeeth Deemed to Be University, Puducherry, India
E-mail: sharonmedico4991@gmail.com
Tel.: +919952967878
ORCID ID: https://orcid.org/0009-0009-4138-8877

Date of submission: 03.12.2025
Date of acceptance: 19.03.2026
Date of publication: 15.04.2026

Conflicts of interest: None
Supporting agencies: None
DOI: https://doi.org/10.3126/ijosh.v16i1.87093

Copyright: This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License

ABSTRACT

Introduction: Employees of the electronics industry are exposed to ergonomic hazards due to repetitive tasks, prolonged standing, awkward posture, and sustained near work activities resulting in work-related musculoskeletal disorders (WMSD) and vision problems. The presence of these hazards could affect the productivity and well-being of the individual. The study was conducted to estimate the prevalence of WMSDs and vision problems among the employees and to assess factors associated with these occupational health outcomes.

Methods: A cross-sectional study was done during December 2024 – January 2025 among 259 employees of an electronics company in Chennai using simple random sampling. A semi-structured questionnaire containing demographic details and work profile, Nordic musculoskeletal questionnaire to assess the prevalence of work-related musculoskeletal disorders and a questionnaire to assess the prevalence of vision problems were used for collecting data. Data was entered in MS excel and analyzed using SPSS version 16. Descriptive statistics were used, and associations were tested using the Chi-square test with odds ratios and 95% confidence intervals.

Results: The mean age of the participants was 24.16 ± 4.03 years and 76.1% were women. The prevalence of WMSDs was 61.4% and vision problems were reported by 40.2%. The shoulder (52.1%) and neck (49%) were the most commonly affected body regions. Eye strain (49%) was the most frequent visual complaint. WMSDs and vision problems showed significant associations with gender, job process, work shift, work experience, and health-related leave taken ($p < 0.05$).

Conclusion: The study showed a high prevalence of WMSD and vision problems in the electronics workforce. These findings highlight the need for ergonomics risk assessment and routine health screening to enable early identification and prevention of these occupational health problems.

Keywords: Electronics Industry, Ergonomics, Occupational Health, Vision Problems, Work-related Musculoskeletal Disorders.

Introduction

Occupational hazards have a wide range of physical, ergonomic, and environmental risks encountered in the workplace. The electronics component manufacturing industry requires its employees to stand for long hours on the assembly line while making the product, as well as to use microscopes for quality checks of the final product. This exposes them to multiple ergonomic and visual stressors. These occupational exposures increase the risk of developing work-related

musculoskeletal disorders (WMSDs) and vision-related symptoms, both of which can adversely affect workers' functional capacity, work performance, and overall well-being.[1] Work-related Musculoskeletal Disorders are diseases and disorders of the musculoskeletal system and connective tissue due to overexertion or repetitive motion induced by the work environment, leading to pain and discomfort in the body.[2] According to the World Health Organization (WHO), musculoskeletal disorders are the most frequent reasons for disability and restrictions on daily functioning and finding meaningful employment.[3]

With over 149 million years lived with disability (YLDs) or 17% of all YLDs worldwide, musculoskeletal diseases are the main cause of YLDs worldwide. According to the 2019 Global Burden of Disease report, low back pain accounts for the majority of musculoskeletal diseases, which together account for 7.4% of YLDs worldwide.[4] Workers in assembly-line manufacturing, particularly in electronics industries, are especially vulnerable due to repetitive hand movements, static postures, and inadequate ergonomic design of workstations. A study done among technical workers also demonstrated a high prevalence of musculoskeletal disorders, particularly affecting the neck, shoulder and upper back regions due to similar occupational exposures.[5] Long-term microscope usage and continuous near work may also precipitate visual fatigue, eye strain and symptoms of asthenopia among electronics workers.[6] Occupational exposure to microscope-related lighting and visual demands has been identified as a potential risk factor among laboratory workers.[7] Vision-related problems not only reduce work efficiency but may also contribute to errors, reduced concentration, and increased occupational stress.

Understanding the prevalence and determinants of these occupational health problems is essential for planning effective preventive strategies, improving workplace ergonomics, and strengthening occupational health services. Thus, the present study was conducted to estimate the prevalence of work-related musculoskeletal disorders and vision problems among employees of an electronics company in Chennai and to assess factors associated with these occupational health outcomes.

Methods

A cross-sectional study was conducted to assess the work-related musculoskeletal disorders and vision problems among employees of an electronics company in Chennai from December 2024 to January 2025. The sample size was calculated using the formula: $n = z^2pq / d^2$, assuming a prevalence (p) of WMSD as 62% according to Jain and Shetty study in Mangalore,[8] with a 95% confidence level and relative precision of 6.2% with 10% additional allowance for non-response rate, the final sample size of 259 was derived. A list of electronics manufacturing companies registered in Tamil Nadu was obtained from the Ministry of Corporate Affairs. Companies employing skilled and semi-skilled workers were identified, and one company was selected using simple random sampling. Employees who were involved in production-related activities and had been in the current job position for a minimum of one year were included. Only those who provided written informed consent and were present during the period of data collection were enrolled in the study.

Employees with a documented history of WMSD or vision problems diagnosed prior to joining the industry were excluded. Workers with a history of recent trauma, surgery, or acute illness affecting the musculoskeletal or visual system at the time of data collection were also excluded. From the sampling frame, study participants were chosen using simple random sampling.

Data were collected using a semi-structured questionnaire consisting of socio-demographic and work-related variables, the Standard Nordic Musculoskeletal Questionnaire (to determine site-specific musculoskeletal symptoms in the past 12 months), and the Asthenopia questionnaire (to

assess prevalence of vision problems) which was administered through face-to-face interviews.

The Nordic musculoskeletal questionnaire, developed by Kuorinka et al,[9] in 1987, is a general questionnaire of 40 forced-choice items identifying areas of the body causing musculoskeletal problems. Completion is aided by a body map that indicates nine symptom sites: neck, shoulders, upper back, elbows, lower back, wrists/hands, hips/thighs, knees, and ankles/feet. Respondents were asked if they had any musculoskeletal trouble in the last 12 months which has prevented normal activity and whether they had seen a doctor regarding the site-specific pain.[10] Vision-related problems were evaluated using a modified questionnaire proposed by Ames et al.[11] The questionnaire included items assessing common visual symptoms, such as eye strain, eye fatigue, blurred vision, headache, dryness, and eye discomfort experienced during or after work. Participants were asked to report whether they experienced each symptom during the past one year.

The study was conducted after obtaining ethical clearance from the Institutional Ethics Committee of Madras Medical College, Chennai (ECR/270/Inst./TN/2013/RR-16) and permission from the General Manager of the Electronics Company where the study was carried out. Confidentiality of the information was maintained throughout the study. Microsoft Excel was used to enter the data, and a master chart was created. The master chart's data was also double-checked for any mistakes. The Statistical Package for the Social Sciences (SPSS) version 16 was used to export the master chart for analysis. Descriptive data were analyzed using frequency, percentage, mean, and standard deviation. Chi-square test was used to examine the association between categorical variables. A p-value of less than 0.05 was considered statistically significant.

Results

The study was conducted among employees of an electronics company to assess the prevalence of work-related musculoskeletal disorders and vision problems among 259 participants.

The mean age of the study participants was 24.16 ± 4.03 years, with the majority (74.9%) aged 21 to 30 years. The employees were predominantly women, contributing to 76.1%. About 38.6% did their graduation. Nearly 30.1% are married. Only 3.1% had morbidities like hypertension and asthma. (Table 1)

According to the job process, 58.3% of the employees were in the winding and soldering part, whereas only 18.9% were in quality control. The mean years of working in the current position is 1.93± 1.49 years, with 55.2% having more than 2 years of work experience. Only 32.1% had taken leave in the past year for health reasons, of which about 29% had taken leave from work for more than 3 days. The maximum number of days taken leave for health reasons was 10 days (Table1). The mean number of days taken as leave was 3.13 ± 2.18 days.

The prevalence of work-related musculoskeletal disorders was about 61.4%, and vision problems were about 40.2%. (Table 2) Only 42.7% of the study participants visited the doctor for their work-related musculoskeletal disorder and about 29.8% visited related to their vision. More than half of the employees (59.1%) had never undergone an eye check-up. The most affected body part was the shoulder (52.1%), followed by the neck (49%), for the past one year. Lower prevalence was observed for the elbow (3.5%) and ankle/foot regions (9.3%). (Figure 1)

There was a significant association seen between gender, job process, work shift, work experience, leave taken, and the number of days leave was taken and work-related musculoskeletal disorders. Males had 3.36 times increased odds of having work-related musculoskeletal disorders (WMSD) compared to females.

Table 1: Socio-demographic characteristics of the employees (n=259)

Variables		**Frequency (Percentage)**
Age (In years)	≤ 20	44 (17%)
	21 to 30	194 (74.9%)
	> 30	21 (8.1%)
Gender	Male	62 (23.9%)
	Female	197 (76.1%)
Education	Secondary school	65 (25.1%)
	Higher secondary	57 (22%)
	Diploma	37 (14.3%)
	Professional degree	100 (38.6%)
Marital status	Unmarried/Divorced	181 (69.9%)
	Married	78 (30.1%)
Morbidity	Hypertension	3 (1.2%)
	Asthma	5 (1.9%)
	None	251 (96.9%)

Table 2: Prevalence of occupational health problems and health seeking behavior in the employees for the past one year

Variables		**Frequency & Percentage**
Work related Musculoskeletal disorder	Yes	159 (61.4%)
	No	100 (38.6%)
Seen a doctor for musculoskeletal disorder	Yes	68 (42.7%)
	No	91 (57.3%)
Vision problem	Yes	104 (40.2%)
	No	155 (59.8%)
Seen a doctor for vision problem	Yes	31 (29.8%)
	No	73 (70.2%)
Visits for eye check-up	Zero	153 (59.1%)
	1 visit	57 (22%)
	≥ 2 visits	49 (18.9%)

Employees on the evening shift had 4.54 times the odds of having WMSD compared to those on the morning shift. Those who had taken leave for more than 3 days had 4.82 times increased odds of having WMSD compared to those who had taken less than 3 days leave. (Table 3) The most common problem affecting the vision was eye strain (49%) followed by eye fatigue in 35.1% of the employees. (Figure 2) The least troublesome problem was dry eye, affecting 3.5% of the study participants. There was a significant association between gender, overall job process, work shift, work experience, leave taken, and Vision problems. (Table 4) Males had 5.58 times increased odds of having vision problems compared to females. Workers in the soldering section had 4.71 times higher odds of vision problems compared to workers in the winding section. Employees of the evening shift had 10.22 times increased odds of having vision problems compared to the morning shift. Employees of more than 2 years of work experience had 2.48 times increased odds of having vision problems.

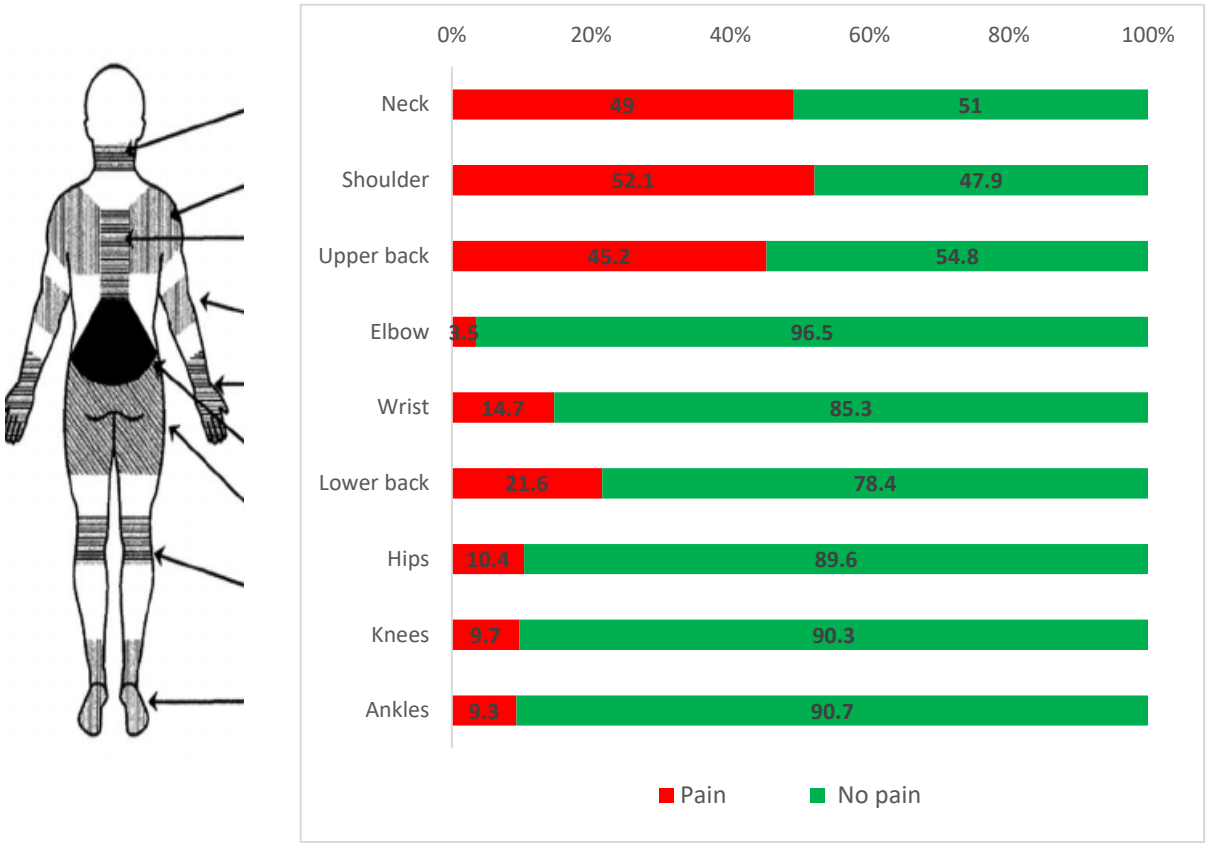


Figure 1: Prevalence of musculoskeletal disorder by body part over the past 1 year

Table 3: Association between work profile and Work-related Musculoskeletal disorders (WMSD)

Factors		WMSD		OR	CI	P value
		Present	Absent			
Gender	Male	50	12	3.36	1.68-6.70	**<0.0001**
	Female	109	88			
Job Process	Winding (Ref)	34	40	1	-	**-**
	Soldering	56	21	3.14	1.59-6.18	**0.0009**
	Epoxy Potting	36	23	1.84	0.92-3.69	0.085
	Quality Check	33	16	2.43	1.15-5.16	**0.021**
Shift	Evening	45	8	4.54	2.03-10.11	**0.0002**
	Morning	114	92			
Work experience	≥ 2 years	99	44	2.1	1.26-3.49	**0.004**
	1- 2 years	60	56			
Taken leave	Yes	64	20	2.69	1.50-4.83	**0.001**
	No	95	80			
No of days taken leave	> 3 days	22	2	4.82	1.02-22.75	**0.0465**
	≤ 3 days	41	18			

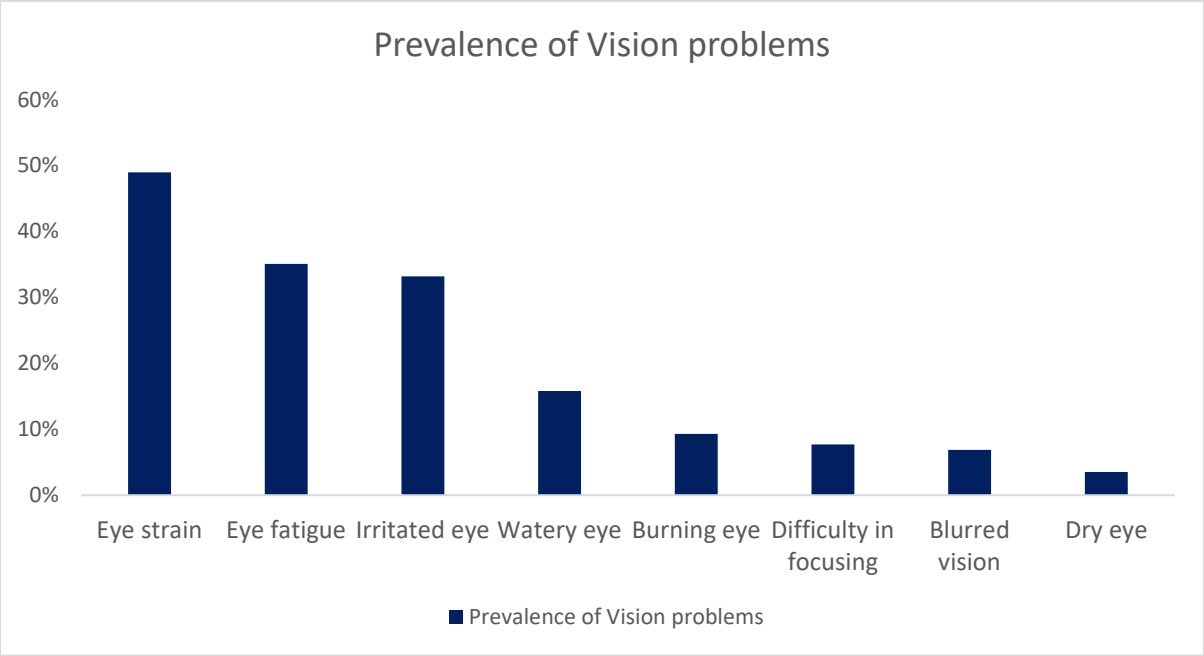


Figure 2: Prevalence of Vision problems in the employees

Table 4: Association between work profile and Vision problems

Factors		Vision problem		OR	CI	P value
		Present	Absent			
Gender	Male	44	18	5.58	2.98-10.44	**<0.0001**
	Female	60	137			
Job Process	Winding (Ref)	17	57	1	-	**-**
	Soldering	45	32	4.71	2.30-9.64	**<0.0001**
	Epoxy Potting	15	44	1.14	0.52-2.52	0.73
	Quality Check	27	22	4.11	1.88-8.98	**0.0004**
Shift	Evening	43	10	10.22	4.82-21.64	**<0.0001**
	Morning	61	145			
Work experience	≥ 2 years	71	72	2.48	1.47-4.17	**0.001**
	1- 2 years	33	83			
Taken leave	Yes	48	36	2.83	1.65-4.84	**0.001**
	No	56	119			
No of days taken leave	> 3 days	17	6	2.74	0.95-7.89	0.06
	≤ 3 days	31	30			

Discussion

The present study assessed the prevalence of WMSD and vision-related problems among employees of an electronics manufacturing company in Chennai. A high prevalence of both conditions was observed, with nearly two-thirds of the employees reporting musculoskeletal symptoms and over two-fifths experiencing one or more vision-related symptoms during the past year. These findings underscore the occupational health burden faced by workers in electronics manufacturing settings.

The prevalence of WMSD in the present study was 61.4%, higher than that reported by Yin et al. in China (40.6%).[12] The most affected sites in our study were the shoulder (52.1%) and the neck (49%), which is consistent with the study done by

Daneshmandi et al. among assembly line workers in an electronics company in Iran, where the prevalence was 63.8% for the neck and 60.9% for the shoulders.[13] Similar findings were also seen in employees of the manufacturing sector, the petrochemical industry, the hand weaving industry, and the healthcare industry, where the prevalence ranged from 25% to 56% . This may be attributed to the same kind of repetitive movements and forward head posture.[14] Upper body musculoskeletal strain is an ergonomic risk in occupations requiring precision work and prolonged static posture.

In our study, about 42.7% sought medical consultation for work-related musculoskeletal disorders, in contrast to the study by Akinpelu et al. in Nigeria among sewing machine operators, where only 4% sought medical consultation. This could be due to the operators' socioeconomic status or to the pain not being severe enough to warrant a visit to the doctor.[15] The male employees had a higher risk of developing work-related musculoskeletal disorders compared to females [OR = 3.36, 95% CI (1.68, 6.70)], which is in line with the study done by Kee in Korea [OR = 1.59, 95% CI (1.51, 1.68)].[16] The employees who had been on the job for more than two years [OR = 2.1, 95% CI (1.26, 3.49)] had a higher risk of developing WMSD, which is in line with the study done by Yang in China and by Roli et. al. in India probably due to the fact that they are more exposed to the same kind of movements than new employees.[1,5]

The prevalence of vision problems among employees was 40.2%, similar to the finding of Untimanon et al. in Thai workers, where the prevalence was 56.4%.[17] The most common symptom was eye strain (49%), followed by eye fatigue (35.1%), which is similar to the study done by Jain and Shetty in Mangalore, where the prevalence for eye fatigue was 59.6% and eye discomfort was 38.3%.[8] Those who had more years of work experience had a higher prevalence of developing visual problems [OR=2.48, 95% CI (1.47, 4.17)], which is similar to the study done by Lin in Taiwan [OR= 1.03, 95% CI (1.01, 1.06)].[18]

Similarly, recent literature has documented significant occupational health challenges, including musculoskeletal strain and visual fatigue, among workers engaged in precision-based and repetitive tasks, such as those in manufacturing and service sectors. The studies by Jayadi Y et al and Kaewjunda J et al. reinforce that prolonged static posture, repetitive hand movements, and visual demands are critical determinants of both musculoskeletal and visual morbidities.[19,20] Similar findings were documented in a Chennai-based study by Sujitha S et al., stating the associated health risks among employees across the petroleum supply chain.[21] The consistency of these findings across different occupational settings strengthens the evidence that ergonomic risk factors play a central role in the development of these conditions and underscores the urgent need for workplace interventions focused on ergonomic redesign, task variation, and periodic health surveillance.

We had limitations, as this study sample was from a single company; the results cannot be generalized, as each company would differ in its working conditions and organizational practices. The assessment of musculoskeletal and vision-related symptoms was based on self-reported information, which may be subject to recall bias and reporting bias. Objective ergonomic assessments and clinical evaluations were not performed, which could have provided more precise estimates of exposure and health status.

Conclusion

This study revealed that employees in the electronics industry experience a high burden of work-related musculoskeletal disorders (61.4%) and vision problems (40.2%). Gender, job process, shift timing, work experience, and health-related leave were significantly associated with both conditions. These findings emphasized an urgent need to strengthen workplace ergonomics, regular awareness and training on workplace posture and stretching exercises to reduce

biomechanical strain on the body. Regular eye screenings and vision care initiatives, such as proper lighting and eye relaxation practices, might reduce vision problems among employees. Integrating these preventive strategies into workplace health policies can ultimately improve workforce well-being, reduce absenteeism, and enhance productivity.

Acknowledgements

The authors sincerely thank all the participants for their valuable time and cooperation. We also extend our gratitude to the experts who contributed their insights and guidance to this study.

References

1. Yang F, Di N, Guo W, Ding W, Jia N, Zhang H, et al. The prevalence and risk factors of work-related musculoskeletal disorders among electronics manufacturing workers: A cross-sectional analytical study in China. BMC Public Health. 2023;23:10. Available from: https://doi.org/10.1186/s12889-022-14952-6
2. Abebaw T, Destaw B, Yenealem DG, Tesfaye AH, Melaku C, Mamaye Y, et al. Work-related musculoskeletal disorders: prevalence, associated factors, and impact on quality of life among kitchen workers in hospitality industry, Bahir Dar City, Northwest Ethiopia, 2023. Front Public Health. 2024 May 14;12. Available from: https://www.frontiersin.org/journals/public-health/articles/10.3389/fpubh.2024.1358867/full
3. WHO Report. Musculoskeletal health. 2022. Available from: https://www.who.int/news-room/fact-sheets/detail/musculoskeletal-conditions
4. Briggs AM, Woolf AD, Dreinhöfer K, Homb N, Hoy DG, Kopansky-Giles D, et al. Reducing the global burden of musculoskeletal conditions. Bull World Health Organ. 2018;96(5):366–8. Available from: https://doi.org/10.2471/BLT.17.204891
5. Roli D, Ali I, Neekhra V. Work Related Musculoskeletal Disorders in Electrical, Telecommunication and Instrument Mechanics of Armed forces. International Journal of Occupational Safety and Health. 2020;10(1):18-27. Available from: https://doi.org/10.3126/ijosh.v10i1.29878
6. George E. Occupational hazards for pathologists: Microscope use and musculoskeletal disorders. Am J Clin Pathol. 2010;133(4):543–8. Available from: https://doi.org/10.1309/AJCPUXDS5KJKRFVW
7. Yılmaz FK, Karakuş S. Laboratory Risk Analysis in a Branch Hospital: The L-type Matrix. International Journal of Occupational Safety and Health. 2024;14(2):194–200. Available from: https://doi.org/10.3126/ijosh.v14i2.53996
8. Jain G, Shetty P. Occupational concerns associated with regular use of microscope. Int J Occup Med Environ Health. 2014;27(4):591–8. Available from: https://doi.org/10.2478/s13382-014-0288-2
9. Kuorinka I, Jonsson B, Kilbom A, Vinterberg H, Biering-Sørensen F, Andersson G, et al. Standardised Nordic questionnaires for the analysis of musculoskeletal symptoms. Appl Ergon. 1987;18(3):233–7. Available from: https://doi.org/10.1016/0003-6870(87)90010-X
10. Crawford JO. The Nordic Musculoskeletal Questionnaire. Occup Med (Lond). 2007;57(4):300–1. Available from: https://doi.org/10.1093/occmed/kqm036
11. Ames SL, Wolffsohn JS, McBrien NA. The development of a symptom questionnaire for assessing visual fatigue during near-vision tasks. Optom Vis Sci. 2005;82(3):168–76. Available from: https://doi.org/10.1097/01.opx.0000156307.95086.6
12. Yin Y, Di N, Guo W, Ding W, Jia N, Wang Z, et al. Multi-site musculoskeletal symptoms in the electronics manufacturing industry: A cross-sectional study. Int J Environ Res Public Health. 2022;19(20):13315. Available from; https://doi.org/10.3390/ijerph192013315
13. Daneshmandi H, Kee D, Kamalinia M, Oliaei M, Mohammadi H. An ergonomic intervention to

relieve musculoskeletal symptoms of assembly line workers at an electronic parts manufacturer in Iran. Work. 2018;61(4):515–21. Available from: https://doi.org/10.3233/WOR-182822

14. Choobineh A, Daneshmandi H, Saraj Zadeh Fard SK, Tabatabaee SH. Prevalence of work-related musculoskeletal symptoms among Iranian workforce and job groups. Int J Prev Med. 2016;7:130. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5200977/

15. Akinpelu AO, Oyewole OO, Odole AC, Ogunbamowo FO. Work-related musculoskeletal pain and health-seeking behaviour among Nigerian sewing machine operators. Trop J Med Res. 2016;19(2):152–8. Available from: https://www.researchgate.net/publication/304793690_Work-related_musculoskeletal_pain_and_health-seeking_behavior_among_Nigerian_sewing_machine_operators

16. Kee D. Characteristics of work-related musculoskeletal disorders in Korea. Int J Environ Res Public Health. 2023;20(2):1024. Available from: https://doi.org/10.3390/ijerph20021024

17. Untimanon O, Pacharatrakul W, Boonmeepong K, Thammagarun L, Laemun N, Taptagaporn S, et al. Visual problems among electronic and jewelry workers in Thailand. J Occup Health. 2006;48(5):407–12. Available from: https://doi.org/10.1539/joh.48.407

18. Lin KH, Su CC, Chen YY, Chu PC. The effects of lighting problems on eye symptoms among cleanroom microscope workers. Int J Environ Res Public Health. 2019;16(1):101. Available from: https://doi.org/10.3390/ijerph16010101

19. Jayadi YD, Lestari F, Tejamaya M, Prasetyo S, Fikawati S, Sugiarti S, et al. Occupational safety and health education for reducing workplace accidents in oil palm plantations. Int J Occup Saf Health. 2025 Dec 16;15(4):361–9. Available from: https://doi.org/10.3126/ijosh.v15i4.76198

20. Kaewjunda J, Jiraponkul C, Neubert MS, Limmongkon Y. Prevalence and factors affecting work-related musculoskeletal disorders among faculty members at Northeastern Universities in Thailand. Int J Occup Saf Health. 2025 Dec 16;15(4):380–90. Available from: https://doi.org/10.3126/ijosh.v15i4.77176

21. Sujitha S, Rajmohan M, Dhamodhar D, Sindhu R, Fathima L, Prabu D, et al. Profiling occupational exposure and associated health risks among employees across the petroleum supply chain in Chennai: a cross-sectional study. Int J Occup Saf Health. 2025 Dec 16;15(4):391–403. Available from: https://doi.org/10.3126/ijosh.v15i4.79543

International Journal of Occupational Safety and Health

ISSN: 2091-0878 (Online) ISSN: 2738-9707 (Print)

Original Article

Safety culture maturity and related risk factors among automotive workers in Malaysia

Hasni Hashim[1], Michi Nursabrina Norhisham[1], Amir Ashraf Jalaludin[1,2], Irniza Rasdi[1], Kulanthayan A/L K.C. Mani @ Subramanian[1], Mohd Rafee Bin Baharudin[1]

[1]Department of Environmental and Occupational Health, Faculty of Medicine and Health Sciences, Universiti Putra Malaysia, Selangor, Malaysia,
[2]Department of Optometry, Rehabilitation & Well-being, Faculty of Health and Life Sciences, Management and Science University, Science Tower, Seksyen 13, 40150 Shah Alam, Selangor

Corresponding author:
Irniza Rasdi,
Associate Professor, Department of Environmental and Occupational Health, Faculty of Medicine and Health Sciences, Universiti Putra Malaysia, Serdang, Selangor
E-mail: irniza@upm.edu.my
Tel.: +603-97692701
ORCID ID: https://orcid.org/0000-0002-1653-0001

Date of submission: 12.03.2025
Date of acceptance: 03.04.2026
Date of publication: 15.04.2026

Conflicts of interest: None
Supporting agencies: Ethical Committee for Research Involving Human Subjects of Universiti Putra Malaysia (JKEUPM)
DOI: https://doi.org/10.3126/ijosh.v16i1.76571

Copyright: This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License

ABSTRACT

Introduction: The automotive industry in Malaysia has a high rate of workplace accidents, highlighting concerns about the effectiveness of safety culture. Safety culture reflects workers' attitudes and behaviors toward safety and can influence accident outcomes. Therefore, this study aims to assess the safety culture maturity level and its associated sociodemographic and occupational factors among automotive workers in Malaysia.

Methods: This cross-sectional study was conducted at one of the largest automotive factories in Malaysia. Survey data were collected for over one month, from early August to September 2022, from 387 workers in the manufacturing division using a non-probability sampling method. A standardized 28-item SASTO questionnaire was administered.

Results: Most respondents were between eighteen and thirty years old (32.3%), male (63.3%), with an education level of Sijil Pelajaran Malaysia (49.1%), working as operators (76.0%), with one to ten years of work tenure (52.7%), and no history of occupational accidents (79.3%). The results indicated that the average level of safety culture maturity among the respondents was 3.46 (SD = 0.94), indicating a proactive stage. Among the aspects of safety culture, the organizational aspect had the highest mean level (M = 3.48, SD = 1.05), followed by the psychological aspect (M = 3.46, SD = 0.82), and the behavioral aspect (M = 3.42, SD = 0.98)In multivariate analysis, significant associations were found between gender (β = 0.145), educational level (β = 0.156), had history of occupational accidents (β = 0.346), and departments (β = 0.171) with the level of safety culture maturity. The most dominant factor was the history of occupational accidents.

Conclusion: The safety culture among workers is generally positive, even with areas identified for improvement. This safety culture is influenced by their sociodemographic and working backgrounds, as well as their history of occupational accidents. Therefore, it is recommended that future intervention strategies to prevent occupational accidents consider these factors to ensure effectiveness.

Keywords: Automotive Industry, Occupational Health, Safety Culture, Cross-Sectional Studies, Risk Factors

Introduction

The automotive industry, a sub-sector of manufacturing also known as the car manufacturing industry, plays a pivotal role in Malaysia. The Institute of Labor Market

Information and Analysis (ILMIA) reported over 10,000 cases of occupational accidents in the manufacturing sector in both 2019 and 2020, including nearly 100 fatalities.[1] This highlights the high incidence of workplace injuries in the industry. In 2021, the Department of Occupational Safety and Health (DOSH) recorded approximately 4,200 occupational accidents in manufacturing, resulting in over 4,000 cases of non-permanent disabilities, 206 cases of permanent disability, and 48 fatalities.[2] However, DOSH emphasized that these figures represent only reported incidents, suggesting a significant number of unreported cases. This underreporting indicates potential gaps in safety management and reporting practices within the sector.

The increasing rate of occupational accidents and illnesses among manufacturing workers has raised concerns about the effectiveness of organizational safety culture. Safety culture encompasses workers' behaviors, perceptions, and beliefs about risk management and safety engagement.[3] This concept gained prominence after the Chernobyl nuclear disaster, where both organizational and individual errors were identified as root causes.[4] Research underscores a strong correlation between safety culture and occupational accident rates.[5] This is further supported by recent occupational safety and health studies highlighting the critical role of workplace safety systems in preventing injuries and improving worker well-being. For instance, a study found that workers actively engaged in safety culture were less likely to cause accidents than those disengaged.[5] Safety culture is closely tied to human beliefs, attitudes, and behaviors toward risk, where individuals unaware of this culture are more prone to unsafe acts.[6] Various accident causation models further highlight the role of human actions in workplace incidents, identifying fundamental patterns leading to accidents.[7] According to the Health and Safety Executive, safety culture comprises psychological, behavioral, and organizational aspects.[8] These dimensions focus on attitudes, actions, and institutional practices, respectively, with the safety culture maturity model serving as a tool to assess organizational safety commitment.

The Hudson Safety Culture Maturity Model conceptualizes safety culture as a progressive ladder with five stages: pathological, reactive, calculative, proactive, and generative.[9] In the pathological stage, safety is viewed as a worker-caused issue addressed only to avoid detection. The reactive phase marks a response-driven focus on safety after accidents. The calculative phase involves management-led safety practices, often without worker involvement. A shift occurs during the proactive phase, in which workers actively participate in safety initiatives. The highest stage, the generative phase, integrates safety as a core organizational value, with all levels actively engaged.[9] Understanding the factors influencing safety culture maturity is essential to establishing a safe work system, particularly in high-risk industries like automotive manufacturing. Recent evidence also indicates that occupational safety and health has become an increasingly important research area globally due to its direct impact on worker productivity and well-being.

Worker demographics significantly influence workplace safety culture. Studies show that factors such as age, education, and cultural background affect safety perception and behavior.[10] Older workers often exhibit higher safety compliance than younger workers, emphasizing the role of age in fostering a strong safety culture.[11] Additionally, education levels and work experience impact safety awareness and the ability to address hazardous situations.[12] Language barriers and cultural differences among foreign workers further complicate safety training and communication.[13] Recognizing these sociodemographic factors is crucial for developing effective safety strategies

The automotive industry remains a cornerstone of Malaysia’s manufacturing sector, contributing 4% to GDP and ranking as ASEAN's third-largest automotive market.[14] This high production demand often results in long working hours and

diverse tasks, increasing the risk of accidents and reduced performance.[15] While a robust safety culture is widely recognized as key to mitigating these risks, data on safety culture in Malaysian industries, particularly in manufacturing, remain scarce.[2] Addressing this gap, this study aims to assess the safety culture maturity level and identify risk factors, including sociodemographic and occupational backgrounds, among automotive industry workers in Malaysia.

Methods

This cross-sectional study was conducted among automotive workers in the manufacturing division of an automotive company located in Perak, Malaysia. Both male and female workers aged 18 and above were included in the study, while those with less than one year of experience were excluded. Data collection was carried out over one month, from early August to September 2022. A minimum sample size of 377 respondents was required, calculated with a 20% allowance for potential missing data. The study successfully obtained responses from 387 participants.

The survey utilized structured questionnaires designed specifically for this study, known as the Safety Culture Assessment Tool for Car Manufacturing Company (SASTO). The survey comprised 28 items, categorized into two distinct sections. Section A contained seven items focusing on demographic information, including age, gender, education level, job role, department, and length of employment. Section B contained 21 questions evaluating safety culture across three aspects: psychological, behavioral, and organizational. These aspects were further categorized into six dimensions: safety priority, organizational learning, involvement, behavior towards risk, procedure adherence, and commitment. Respondents rated their agreement with statements on a Likert scale. The SASTO questionnaire consisted of 28 items measuring three key aspects of safety culture: psychological, behavioral, and organizational. Each item was rated on a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). The overall safety culture maturity level was calculated as the mean of all responses. Scoring was guided by the Hudson Safety Culture Maturity Model (2001), which categorizes organizations into five maturity levels based on average scores. These levels are detailed in Table 1.

A pre-test was conducted with 10% of the target sample to verify clarity and resolve any language-related ambiguities in the Malay-language questionnaire. The questionnaire's internal reliability was validated, yielding a Cronbach's alpha of 0.82. The study employed a purposive sampling method to select the participating automotive company. This company is one of the largest automotive factories producing cars as its main product. Within the company, convenience sampling was used to recruit respondents from six key manufacturing departments: Body Assembly 1, Body Assembly 2, Painting, Trim & Final 1, and Trim & Final 2. Due to restricted access to workers' data, a non-probability sampling approach was deemed suitable. With assistance from the company's Safety, Health, and Environment Department, questionnaires were distributed to employees in these departments. Participants were informed of the study's purpose via the online questionnaire and assured of confidentiality, with the emphasis that their responses would be used solely for research. Ethical approval for the study was obtained from the Ethics Committee for Research Involving Human Subjects at Universiti Putra Malaysia (Reference number: JKEUPM-2022-401). Additionally, permission was granted by the company's Department of Safety, Health, and Environment.

Data analysis was performed using SPSS Version 26.0. Descriptive statistics were used to summarize respondent demographics and safety culture maturity levels. The association between sociodemographic and occupational backgrounds and safety culture maturity was analyzed using the Pearson chi-square test. Multiple Linear Regression analysis was conducted to further

determine these associations. Statistical significance for all hypotheses was set at $p < 0.05$.

Table 1. The scoring method of safety culture maturity level

Scoring	Level of safety culture maturity
0.00 – 1.44	1 (Pathological)
1.45 – 2.44	2 (Reactive)
2.45 – 3.44	3 (Calculative)
3.45 – 4.44	4 (Proactive)
4.45 – 5.00	5 (Generative)

Results

This study successfully recruited 387 respondents from the six main departments within the organization's manufacturing division who completed the questionnaire. This resulted in a 100% response rate. Table 2 presents the respondents' sociodemographic and occupational backgrounds. In terms of sociodemographic characteristics, 125 (32.3%) respondents were aged 18-30 years, 245 (63.3%) were male, and 190 (49.1%) had an educational background of Sijil Pelajaran Malaysia (SPM). The majority of respondents worked in the painting department (42.4%), with most holding operator positions (76.0%). Additionally, most respondents reported 1-10 years of work experience (52.7%), and 79.3% had no record of occupational accidents.

In this research study, safety culture maturity was assessed across three aspects: psychological, behavioral, and organizational. Each aspect was analyzed to determine its contribution to the overall maturity of the safety culture. The mean of the overall safety culture maturity was calculated and rounded off. The scoring method for the safety culture maturity level has been outlined in Table 1, adapted from Hashim (2022). Based on the results, the organizational aspect exhibited the highest mean safety culture score (3.48), followed by the psychological (3.46) and behavioral (3.42) aspects. The overall safety culture maturity among respondents was nearly equivalent across all aspects, with a mean of 3.46. The study referenced the Hudson (2001) Model, in which higher levels indicate greater safety culture maturity within an organization. This suggests that the overall safety culture maturity among the recruited automotive workers was classified as Level 4 (Proactive) after rounding the value up. Similarly, the psychological and organizational aspects were also categorized as proactive among the respondents, while the behavioral dimension was classified as calculative. Under the psychological aspect, two sub-dimensions were assessed: the safety-priority dimension and the organizational-learning dimension. The results indicated that most respondents agreed that their organization tried to balance financial budgets and safety aspects, although they were uncertain about the profitability of this approach. Respondents also agreed that top management encouraged continuous improvement in safety and health within the organization. However, most respondents reported feeling safe to report accidents only at certain times in their workplace. This fear stemmed from concerns about being blamed, highlighting a lack of trust between management and employees that still exists.

Additionally, the behavioral aspect was divided into two factors: employees' safety involvement and their behavior towards risk. The results indicate that management encourages workers to participate in safety-related activities, but only at certain times. It is also observed that most employees provide their full participation and opinions only when prompted by management after accidents, rather than engaging in frequent discussions. Consequently, the level of safety culture maturity among respondents in the behavioral aspect is the lowest among the three aspects, suggesting a lack of worker participation in safety-related issues within the organization.

Safety procedures and safety commitments were the two sub-dimensions assessed under situational aspects. The results reveal that safety audits are comprehensive in all areas, while risk assessments are conducted only in some working areas by the designated personnel. The company also demonstrates full commitment to training for emergency preparedness, and reports are regularly reviewed daily.

The association between sociodemographic and occupational backgrounds with safety culture maturity among respondents was assessed using a Pearson chi-square test with α = .05. Safety culture levels were determined based on the Hudson (2001) Safety Culture Maturity model, which comprises five levels. Levels 1 and 2 were classified as 'Poor,' Level 3 as 'Moderate,' and Levels 4 and 5 as 'Strong.' The analysis considered three aspects of safety culture maturity: psychological, behavioral, and situational aspects. Referring to Table 3 below, three sociodemographic characteristics were considered in this analysis: gender, age groups, and the education level of respondents. The association between two sociodemographic backgrounds and overall safety culture maturity among respondents was found to be statistically significant: gender ($p < .05$) and educational level ($p < .05$). Thus, the null hypothesis is rejected. Regarding gender, it is observed that 58.5% of female workers exhibit a stronger safety culture maturity compared to male workers (43.7%). Furthermore, participants with an educational level of degree and above have the highest percentage of strong safety culture maturity at 62.2%.

Regarding occupational background, four aspects were considered: years of employment, department, position, and history of occupational accidents among automotive workers. The department in which respondents worked was found to be statistically significant in relation to the overall level of safety culture maturity, with $p < .001$. Therefore, the null hypothesis is rejected. Specifically, the Painting department had the highest percentage of respondents (63.4%) with a strong safety culture maturity, while the Trim & Final 2 department had the highest percentage of respondents (40.0%) with a poor level of safety culture maturity. Furthermore, the history of occupational accidents was found to be significantly associated with the overall level of safety culture maturity, with $p < .001$. Hence, the null hypothesis is also rejected. The findings were similar to those for the overall aspect, with age and education level were $p < .05$ significantly associated with it. Furthermore, occupational factors significantly associated with safety culture maturity included department ($p < .05$) and occupational accidents ($p < .05$). Thus, the null hypothesis is rejected.

In terms of the behavioral aspect, gender ($p < .05$) and education ($p < .05$) were found to be significant factors associated with safety culture maturity among the sociodemographic background. Additionally, occupational factors that were found to be statistically significant with safety culture maturity included years of employment ($p < .05$), department ($p < .05$), and history of occupational accidents ($p < .001$). Thus, the null hypothesis is rejected (refer to Table 5).

Table 2. The sociodemographic and occupational background of respondents (N=387)

Characteristics	Frequency, n (%)
Gender	
Male	245 (63.3)
Female	142 (36.7%)
Age Group (in Years)	
18 – 30	125 (32.3)
31 – 40	109 (28.3)
41 – 50	92 (23.8)
51 and above	61 (15.8)
Education Level	
Sijil Pelajaran Malaysia	190 (49.1)
Diploma	93 (24.0)
Degree and above	90 (23.3)
Others	14 (3.6)
Years of Employment (in Years)	
1 – 10	204 (52.7)
11 – 20	120 (31.0)
21 and above	63 (16.3)
Department	
Body Assembly 1	33 (8.5)
Body Assembly 2	38 (9.8)
Painting	164 (42.4)
Stamping	55 (14.2)
Trim & Final 1	42 (10.9)
Trim & Final 2	55 (14.2)
Position	
Operator	294 (76.0)
SG1 – SG4	55 (14.2)
SG5 and above	38 (9.8)
Occupational accident	
Yes	80 (20.7)
No	307 (79.3)

Table 3. The association between sociodemographic and occupational background with overall safety culture maturity (N = 387)

Characteristics	Overall safety culture maturity			X^2	p-value
	Poor n (%)	Moderate n (%)	Strong n (%)		
Gender					
Male	52 (21.2)	86 (35.1)	107 (43.7)	12.973	**0.002***
Female	12 (8.5)	47 (33.1)	83 (58.5)		
Age Group (in Years)					
18 – 30	16 (12.8)	37 (29.6)	72 (57.6)		
31 – 40	19 (17.4)	39 (35.8)	51 (46.8)	6.597	0.360
41 – 50	17 (18.5)	32 (34.8)	43 (46.7)		
> 51	12 (19.7)	25 (41.0)	24 (39.3)		
Education Level					
Sijil Pelajaran Malaysia	38 (20.0)	71 (37.4)	81 (42.6)		
Diploma	12 (12.9)	38 (40.9)	43 (46.2)	16.380	**0.012***
> Degree	11 (12.2)	23 (25.6)	56 (62.2)		
Others	3 (21.4)	1 (7.1)	10 (71.4)		
Years of Employment (in Years)					
1 – 10	24 (11.8)	71 (34.8)	109 (53.4)		
11 – 20	26 (21.7)	43 (35.8)	51 (42.5)	8.234	0.083
21 and above	14 (22.2)	19 (30.2)	30 (47.6)		

Department					
Body Assembly 1	4 (12.1)	11 (33.3)	18 (54.5)		
Body Assembly 2	9 (23.7)	11 (28.9)	19 (47.4)		
Painting	11 (6.7)	49 (29.9)	104 (63.4)	50.033	**<0.001***
Stamping	10 (18.2)	25 (45.5)	20 (36.4)		
Trim & Final 1	8 (19.0)	18 (42.9)	16 (38.1)		
Trim & Final 2	22 (40.0)	19 (34.5)	14 (25.5)		
Position					
Operator	48 (16.3)	101 (34.4)	145 (49.3)		
SG1 – SG4	13 (23.6)	19 (34.5)	23 (41.8)	4.597	0.331
SG5 & above	3 (7.9)	13 (34.2)	22 (57.9)		
Occupational accident					
Yes	34 (42.5)	33 (41.3)	13 (16.3)	64.655	**<0.001***
No	30 (9.8)	100 (32.6)	177 (57.7)		

Note: *p*-value is significant when <0.05

Table 4. The association between sociodemographic and occupational background with the psychological safety culture maturity aspect (N = 387)

Characteristics	Psychological safety culture maturity aspect			X^2	p-value
	Poor n (%)	Moderate n (%)	Strong n (%)		
Gender					
Male	27 (11.0)	94 (38.4)	124 (50.6)	7.328	**0.026***
Female	11 (7.7)	39 (27.5)	92 (64.8)		
Age Group (in Years)					
18 – 30	12 (9.6)	37 (29.6)	76 (60.8)		
31 – 40	12 (11.0)	40 (36.7)	57 (52.3)		
41 – 50	9 (9.8)	31 (33.7)	52 (56.6)	3.195	0.784
> 51	5 (8.2)	25 (41.0)	31 (50.8)		
Education Level					
Sijil Pelajaran Malaysia	21 (11.1)	81 (42.6)	88 (46.3)		
Diploma	12 (12.9)	23 (24.7)	58 (62.4)		
> Degree	4 (4.4)	25 (27.8)	61 (67.8)	17.782	**0.007***
Others	1 (7.1)	4 (28.6)	9 (64.3)		
Years of Employment (in Years)					
1 – 10	21 (10.3)	63 (30.9)	120 (58.8)		
11 – 20	13 (10.8)	48 (40.0)	59 (49.2)	4.157	0.385
21 and above	4 (6.3)	22 (34.9)	37 (58.7)		
Department					
Body Assembly 1	4 (12.1)	8 (24.2)	21 (63.6)		
Body Assembly 2	2 (5.3)	14 (36.8)	22 (57.9)		
Painting	9 (5.5)	50 (30.5)	105 (64.0)		
Stamping	6 (10.9)	20 (36.4)	29 (52.7)	23.335	**0.010***
Trim & Final 1	6 (14.3)	15 (35.7)	21 (50.0)		
Trim & Final 2	11 (20.0)	26 (47.3)	18 (32.7)		
Position					
Operator	48 (16.3)	101 (34.4)	157 (53.4)		
SG1 – SG4	13 (23.6)	19 (34.5)	34 (61.8)	4.698	0.320
SG5 & above	3 (7.9)	13 (34.2)	25 (65.8)		
Occupational accident					
Yes	21 (28.3)	36 (45.0)	23 (28.7)	44.280	**<0.001***
No	17 (5.5)	97 (31.6)	193 (62.9)		

Note: *p*-value is significant when <0.05

Table 5. The association between sociodemographic and occupational background with behavioral safety culture maturity aspect (N = 387)

Characteristics	Behavioral safety culture maturity aspect			X^2	p-value
	Poor n (%)	Moderate n (%)	Strong n (%)		
Gender					
Male	53 (21.6)	89 (36.3)	103 (42.0)	6.654	**0.036***
Female	18 (12.7)	48 (33.8)	76 (53.5)		
Age Group (in Years)					
18 – 30	16 (12.8)	39 (31.2)	70 (56.0)		
31 – 40	19 (17.4)	44 (40.4)	46 (42.2)		
41 – 50	23 (25.0)	32 (34.8)	37 (40.2)	9.911	0.128
> 51	13 (21.3)	22 (36.1)	26 (42.6)		
Education Level					
Sijil Pelajaran Malaysia	44 (23.2)	75 (39.5)	71 (37.4)		
Diploma	12 (12.9)	36 (38.7)	45 (48.4)		
> Degree	12 (13.3)	26 (28.9)	52 (57.8)	21.497	**0.001***
Others	3 (21.4)	0 (00.0)	11 (78.6)		
Years of Employment (in Years)					
1 – 10	26 (12.7)	72 (35.3)	106 (52.0)		
11 – 20	26 (21.7)	50 (41.7)	44 (36.7)	16.546	**0.002***
21 and above	19 (30.2)	15 (23.8)	29 (46.0)		
Department					
Body Assembly 1	4 (12.1)	12 (36.4)	17 (51.5)		
Body Assembly 2	9 (23.7)	11 (28.9)	18 (47.4)		
Painting	16 (9.8)	54 (32.9)	94 (57.3)		
Stamping	15 (27.3)	20 (36.4)	20 (36.4)	31.176	**0.001***
Trim & Final 1	8 (19.0)	19 (45.2)	15 (35.7)		
Trim & Final 2	19 (34.5)	21 (38.2)	15 (27.3)		
Position					
Operator	54 (18.4)	108 (36.7)	132 (44.9)		
SG1 – SG4	12 (21.8)	18 (32.7)	25 (45.5)	2.863	0.581
SG5 & above	5 (13.2)	11 (28.9)	22 (57.9)		
Occupational accident					
Yes	34 (42.5)	32 (40.0)	14 (17.5)	50.697	**<0.001***
No	37 (12.1)	105 (34.2)	165 (53.7)		

Note: *p*-value is significant when <0.05

The association between all sociodemographic backgrounds and situational aspects of safety culture maturity was analyzed in this study, as shown in Table 6. The results indicated significant associations with gender ($p < .05$), age groups ($p < .05$), and education level ($p < .05$). Regarding age groups, most workers in the 18 to 30 years old range (62.4%) exhibited a strong safety culture compared to other age groups. Conversely, most workers aged 51 and above (31.1%) demonstrated poor safety culture maturity. Additionally, occupational information was analyzed to determine its association with the situational aspect of safety culture maturity. The results mirrored those of the overall safety culture aspect, with both department ($p < .001$) and occupational accidents ($p < .001$) significantly associated with safety culture maturity. Hence, the null hypothesis is rejected. Table 7 presents the results of the multiple linear regression used to predict the association between sociodemographic factors and the overall safety culture maturity, adjusting for respondents' occupational background. Only the variables found to be significant in the Pearson chi-square test were included in the regression analysis. Prior to this study, preliminary analyses were conducted to ensure that no violations of the assumptions of normality, linearity, multicollinearity, and homoscedasticity occurred.

In combination, gender, education level, accident experience, and department accounted for a significant 22.3% of the variability in safety

culture maturity, with R2 = 0.223, adjusted R2 = 0.215, F (4, 382) = 27.462, p < 0.001. Unstandardized (B) and standardized (ß) coefficients, standard error (S.E), and t for each predictor in the regression model were reported in Table 7. According to the table, an increase of one level of education will increase safety culture maturity by 0.156, while holding the other significant characteristics constant. For gender, female automotive workers will increase the level of safety culture maturity by 0.145 compared to males, while holding the rest constant. The result for the department shows that workers in Body Assembly 1 and Body Assembly 2 had an increase in safety culture maturity of 0.171. The strongest association between the characteristics tested was the history of occupational accidents among workers, where those who had not experienced any accident accounted for an increase in safety culture maturity level by 0.346 while holding the others constant

Table 6. The association between sociodemographic and occupational background with situational safety culture maturity aspect (N = 387)

Characteristics	Situational safety culture maturity aspect			X^2	p-value
	Poor n (%)	Moderate n (%)	Strong n (%)		
Gender					
Male	63 (25.7)	68 (27.8)	114 (46.5)	9.257	**0.010***
Female	19 (13.4)	39 (27.5)	84 (59.2)		
Age Group (in Years)					
18 – 30					
31 – 40	17 (13.6)	30 (24.0)	78 (62.4)		
41 – 50	21 (19.3)	36 (33.0)	52 (47.7)	14.548	**0.024***
> 51	25 (27.2)	25 (27.7)	42 (45.7)		
	19 (31.1)	16 (26.2)	26 (42.6)		
Education Level					
Sijil Pelajaran Malaysia					
Diploma	48 (25.3)	57 (30.0)	85 (44.7)		
> Degree	16 (19.5)	28 (30.1)	49 (52.7)	12.755	**0.047***
Others	14 (15.6)	22 (24.4)	54 (60.0)		
	4 (28.6)	0 (0.0)	10 (71.4)		
Years of Employment (in Years)					
1 – 10					
11 – 20	32 (15.7)	57 (53.3)	115 (56.4)	8.697	0.069
21 & above	33 (27.5)	34 (28.3)	53 (44.2)		
	17 (27.0)	16 (25.4)	30 (47.6)		
Department					
Body Assembly 1	5 (15.2)	11 (33.3)	17 (51.5)		
Body Assembly 2	13 (34.2)	6 (15.8)	19 (50.0)		
Painting	16 (9.8)	40 (24.4)	108 (65.9)		
Stamping	12 (21.8)	22 (40.0)	21 (38.2)	51.359	**<0.001***
Trim & Final 1	11 (26.2)	15 (35.7)	16 (38.1)		
Trim & Final 2	25 (45.5)	13 (23.6)	17 (30.9)		
Position					
Operator	60 (20.4)	80 (27.2)	154 (52.4)		
SG1 – SG4	16 (29.1)	16 (29.1)	23 (41.8)	3.462	0.484
SG5 & above	6 (15.8)	11 (28.9)	21 (55.3)		
Occupational accident					
Yes	35 (43.8)	30 (37.5)	15 (18.8)	48.475	**<0.001***
No	47 (15.3)	77 (25.1)	183 (59.6)		

Note: *p*-value is significant when <0.05

Table 7. The multiple linear regression between predictor variables and overall safety culture maturity aspects (N = 387)

Characteristics	*B*	*ß*	S.E	*t*	*p*
Constant	38.789		5.399	7.185	**<0.001***
Gender	5.559	0.145	1.736	3.202	**<0.001***
Education Level	3.155	0.156	0.916	3.443	**0.001***
History of occupational accident	15.821	0.346	2.098	7.541	**0.001***
Department	-2.220	0.171	0.596	3.724	**<0.001***

Note: *B* = Unstandardized *B*, ß = standardized Beta, S.E = Standard Error, *p*-value is significant when < .05

Discussion

The overall level of safety culture maturity among respondents is almost entirely in the proactive stage (Level 4). This result aligns with findings from a study of steel manufacturers in Malaysia, in which the level of safety culture maturity was similarly classified as a proactive stage. This stage reflects an organizational culture where strong leadership and sustained commitment from top management drive continuous improvements in safety practices. Previous research has also demonstrated that leadership-driven interventions play a critical role in enhancing safety outcomes.[17] These efforts highlight a widespread awareness and prioritization of safety throughout the workplace.[10] Recent studies published in the International Journal of Occupational Safety and Health have highlighted the increasing global importance of occupational safety and health in improving worker well-being and productivity.[24,25]

Under the psychological aspect, two subdimensions have been assessed: the safety-priority dimension and the organizational-learning dimension. The importance of prioritizing occupational safety and health (OSH) within an organization's economic framework has been widely discussed for decades.[8] Dorman defines the economic role of OSH as a means to provide safe and profitable working conditions, emphasizing the importance of addressing indirect financial losses caused by occupational accidents and diseases.[8]

The behavioral aspect is divided into two factors: employees' safety involvement and their behavior towards risk. Workers' involvement in the safety management system is essential for improving safety culture maturity and reducing occupational accidents.[20] A study found a negative correlation between employees' safety involvement and the Total Recordable Incident (TRC) rate, indicating that limited participation often stems from reactive rather than proactive management practices.[23] Employees may be unaware of their right to participate in safety decisions, and employers often fear that such involvement could lead to unreasonable demands.[5] Organizational pressure has also been identified as a contributing factor to underreporting of workplace incidents.[21] This situation highlights the need for inclusive practices, particularly among employees engaged in high-risk tasks requiring adherence to safe procedures.[5] As a result, the behavioral aspect scored lowest in safety culture maturity, primarily due to limited worker participation in safety-related issues. Moreover, management commitment significantly influences employee perceptions of safety and readiness to adopt safe practices.[1,9] A strong safety climate has been shown to positively influence overall safety performance in organizations.[22]

The results indicate that the organization exhibits a high level of safety culture maturity among workers in the manufacturing division. However, there is room for improvement. It is recommended that organizations adopt a 'Just culture' that fosters an open reporting environment where safety discussions are free from fear of negative repercussions or blame.[1,3] Employers should encourage a high-trust environment that balances accountability and

tolerance for errors, differentiating between acceptable and unacceptable actions.[3] Additionally, implementing Behavior-Based Safety (BBS) programs could enhance employees' safety involvement.[2] Such programs aim to transform unsafe behaviors into safe practices through systematic training and fostering individual responsibility for accident-prone behaviors.[3]

This study contrasts with a previous study in an academic setting, which found no significant association between gender factors, education level, and safety culture. However, it aligns with another study in academic settings, in which both gender and education level were found to be associated with safety culture.[12] Research on safety culture maturity among manufacturing workers in Kuantan also found a high correlation between the educational level of workers and their safety perceptions. Over 50% of women among respondents possessed a strong level of safety culture compared to men (43.7%). Earlier studies have concluded that gender plays a significant role in safety perceptions. Hitchcock claimed that women are more detail-oriented when evaluating moderate-to-high risks than men.[15] As women tend to associate with feminine traits, including sensitivity, they may have a higher level of safety culture maturity than men. Based on the findings above, workers with tertiary education have the highest safety culture maturity (62.3%).

In several works of literature, education is defined as the process by which an individual obtains knowledge and information and turns it into value through their cognitive capabilities. While reasoning a task, a person is believed to use their cognitive capabilities from a cognitive-behavioral perspective.[31] Hence, it is believed that a high level of education can increase workers' rationale for their occupational safety judgment and behavior.[11] Furthermore, there was no significant association between age groups and overall safety culture maturity, which obtained similar results as a previous study.[19] Approximately 60% of younger respondents have a high safety culture maturity level, compared with older workers. Older workers may experience declines in physiological systems, including cognitive skills, such as response time to near-miss accidents. [19] Occupational stress and job-related factors may also influence workers' health and safety outcomes.[18] This aligns with findings where the higher age group was found to have poor safety culture maturity among workers.[16] However, Crawford et al.[4] suggested that some older workers may perform comparably to their younger colleagues, depending on individual factors. Thus, safety culture is unlikely to be affected solely by age groups within an organization.

Additionally, 57.7% of respondents with strong safety culture maturity reported no history of occupational accidents in their workplace. The history of occupational accidents showed the strongest association with the safety culture maturity aspect. As there is still a lack of recent studies correlating occupational accidents with safety culture maturity, few comparisons can be made. However, the findings align with a previous study on the relationship between workers' safety culture and accidents in Poland in 2004, which found that safety culture is linked to positive behaviors, such as protecting one's life from danger.[3] Hence, it is reasonable to assume that organizations with good safety culture tend to have lower accident rates than those with poor safety culture.[16] Furthermore, literature suggests that workers' history of occupational accidents tends to increase predictive risky behaviors for those who have witnessed such incidents.

Conclusion

In conclusion, the findings indicate that respondents' overall safety culture maturity falls within the proactive stage. The psychological and situational aspects of safety culture maturity are similarly classified as proactive, while the behavioral aspect remains slightly lower in maturity. The study also found significant

associations between safety culture maturity and sociodemographic factors, particularly gender and educational level. Occupational backgrounds, such as the department in which workers are placed and whether they have experienced workplace accidents, also influence the maturity of safety culture. Among these, the history of occupational accidents emerged as the most influential factor associated with safety culture maturity. Future research on safety culture maturity should focus more on the automotive industry, given its significant contribution to the country's economy. Highlighting the occupational safety and health aspects in this industry is crucial to providing workers with a safe and comfortable working environment. Additionally, based on the findings of this study, further research should focus on selected sociodemographic and occupational backgrounds that are significantly associated with safety culture maturity. This could help policymakers develop more effective intervention programs. Finally, since this study only focuses on one specific automotive company, future research could include automotive workers from various companies in Malaysia to provide a more representative sample and determine the average level of safety culture maturity in the country.

Acknowledgements

The authors express their gratitude to the Ethical Committee for Research Involving Human Subjects of Universiti Putra Malaysia (JKEUPM) for granting ethical approval for the research. They also extend their appreciation to the automotive organization for granting permission to conduct the study. Finally, the authors acknowledge and thank all respondents who volunteered to participate in the study and for their cooperation during data collection.

References

1. Amalia D. Promoting just culture for enhancing safety culture in aerodrome airside operation. Int J Sci Technol Res. 2019;8(10):260-6. Available from: https://www.researchgate.net/publication/341230467
2. Arblaster M. Safety regulation of air traffic management. Air Traffic Management: Economics, Regulations and Governance. 2018; 87-115. Available from: https://doi.org/10.1016/B978-0-12-811118-5.00005-9
3. Aytac S, Dursun S. The effect on the safety culture of occupational accidents and safety behaviour: The case of Turkey. 38th Int Acad Conf, Prague. 2018. Available from: https://doi.org/10.20472/IAC.2018.038.005
4. Crawford JO, Davis A, Cowie H, Dixon K, Graveling R, Belin A, et al. The ageing workforce: Implications for occupational safety and health. J Constr Eng Manag. 2016. Available from: https://www.researchgate.net/publication/313420016_The_ageing_workforce_implications_for_occupational_safety_and_health_a_research_review
5. Decamp W, Herskovitz K. Theories of accident causation. Security Supervision and Management: Theory and Practice of Asset Protection. Elsevier Science. 2015:71-8. Available from: https://doi.org/10.1016/B978-0-12-800113-4.00005-5
6. Department of Occupational Safety and Health. Occupational accidents statistics by sector until December 2021. 2021. Available from: https://www.dosh.gov.my
7. Demirkesen S, Arditi D. Construction safety personnel's perception of safety training practices. Int J Proj Manag. 2015;33(5):1160-9. Available from: https://doi.org/10.1016/j.ijproman.2015.01.007
8. Dorman P. The economics of safety, health, and well-being at work: An overview. InFocus Program on SafeWork, International Labour

Organization. 2000. Available from: https://bit.ly/3iM6ip7

9. Flin R, O'Dea A, Yule S. Leadership behaviours for maximising safety. J Pet Technol. 2002;54:28-32. Available from: https://doi.org/10.2118/73939-MS

10. Grebensek MV, Kosel T. Safety culture assessment – Optimization of existing practice. Int J Traffic Transp Eng. 2015;5(4):360-70. Available from: https://doi.org/10.7708/ijtte.2015.5(4).02

11. Gyekye SA, Salminen S. Educational status and organizational safety climate: Does educational attainment influence workers' perceptions of workplace safety? Saf Sci. 2009;47(1):20-8. Available from: https://doi.org/10.1016/j.ssci.2007.12.007

12. Hamedon TR, Syukran M, Amirah I, Manaf RA. Knowledge, attitude, and practice regarding work safety culture among staff in the faculty of medicine and health sciences, Universiti Putra Malaysia. Int J Public Health Clin Sci. 2015;2(5):2289-7577. Available from: https://www.researchgate.net/publication/285580996

13. Health and Safety Executive. A review of safety culture and safety climate literature for the development of safety culture inspection toolkit. 2005. Available from: https://books.google.com.np/books/

14. Hudson P. Aviation safety culture. In: Proceedings of Safeskies 2001: Managing Aviation Safety in a Globalised World; 2001 Nov 1-2; Canberra, Australia. p. 1-23.

15. Institute of Labour Market Information Analysis. National occupational accidents 2021. 2021. Available from: https://www.ilmia.gov.my/index.php/en/bda-noa2021

16. Isa AAM, Wahab WA, Omar RC, Nordin MZM, Taha H, Roslan R. Impact of employees' age and work experience on safety culture at the workplace. E3S Web Conf. 2021;325. Available from: https://doi.org/10.1051/e3sconf/202132506007

17. Jasiulewicz-Kaczmarek M, Szwedzka K, Szczuka M. Behaviour-based intervention for occupational safety – Case study. Procedia Manuf. 2015;3:4876-83. Available from: https://doi.org/10.1016/j.promfg.2015.07.615

18. Koekemoer FE, Mostert K. Job characteristics, burnout, and ill health of employees within the South African chemical industry. Saf Sci. 2010;48(6):707-14. Available from: https://doi.org/10.1177/008124630703700110

19. Mearns K, Yule S. The role of national culture in determining safety performance: Challenges for the global oil and gas industry. Saf Sci. 2009;47(6):777-85. Available from: https://doi.org/10.1016/j.ssci.2008.01.009

20. Mullen J. Investigating factors that influence individual safety behaviour at work. J Saf Res. 2004;35(3):275-85. Available from: https://doi.org/10.1016/j.jsr.2004.03.011

21. Probst TM, Graso M. Pressure to produce = Pressure to reduce accident reporting? Accid Anal Prev. 2013;59:580-7. Available from: https://doi.org/10.1016/j.aap.2013.07.020

22. Wu TC, Chen CH, Li CC. A correlation among safety leadership, safety climate, and safety performance. J Loss Prev Process Ind. 2008;21(3):307-18. Available from: https://doi.org/10.1016/j.jlp.2007.11.001

23. Zohar D. Modifying supervisory practices to improve subunit safety: A leadership-based intervention model. J Appl Psychol. 2002;87(1):156-63. Available from: https://doi.org/10.1037/0021-9010.87.1.156

24. Gautam P, Khadka TB, Mishra AK. Occupational safety and health (OSH) in Nepal: Current situation and way forward. Int J Occup Saf Health. 2025;15(4):475–85. Available from: https://doi.org/10.3126/ijosh.v15i4.83797

25. Mahat D, Neupane D, Shrestha SK. A decade in focus: occupational health and safety research trends – a bibliometric approach. Int J Occup Saf Health. 2025;15(2):308–26. Available from: https://doi.org/10.3126/ijosh.v15i2.64809

International Journal of Occupational Safety and Health

ISSN: 2091-0878 (Online) ISSN: 2738-9707 (Print)

Original Article

Sleep specialist – defined phenotypes in healthcare staff: a cross-sectional study

Vlami K,[1,3] Riza E,[2] Karakatsani A,[3] Kogevinas M,[4] Farantos G,[1] Verykakis E,[3] Dounias G[1]

[1] Occupational & Environmental Health, Dept Public Health Policy, School of Public Health, University of West Attica, Athens, Greece.
[2] Department of Hygiene, Epidemiology and Medical Statistics Medical School, National and Kapodistrian University of Athens, Athens, Greece.
[3] 2nd Pulmonary Department, School of Medicine, National and Kapodistrian University of Athens, "ATTIKON" University Hospital, Haidari, Athens, Greece.
[4] Barcelona Institute for Global Health (ISGlobal), Barcelona, Spain.

ABSTRACT

Introduction: Healthcare professionals face irregular work schedules and sleep disruption. Identifying sleep–function phenotypes may support early prevention and occupational performance.

Methods: Exploratory, cross-sectional study aimed to characterize sleep parameters and work-related conditions through certified sleep specialist interviews, defining clinically meaningful sleep phenotypes in healthcare workers. This single-center cross-sectional study was conducted between December 2021 and February 2022 in a tertiary hospital. Interviews captured occupational and sleep-related parameters by a sleep specialist. Validated Greek versions of the Pittsburgh Sleep Quality Index (PSQI), Athens Insomnia Scale (AIS), and Epworth Sleepiness Scale (ESS) were administered. Data collection involved structured questionnaires and statistical analysis using STATA/IC software.

Results: Among 38 healthcare professionals, most were medical/nursing staff (71%), one-quarter worked rotating shifts (26%), and the majority reported short sleep duration (74% <7 h). Unadjusted analyses indicated that poorer sleep was associated with younger age, reduced job performance, cognitive strain, morning headaches, and being overweight, whereas evening-type individuals reported fewer sleep complaints. In adjusted models, however, chronotype remained the only independent predictor of sleep disturbance, whereas reduced job performance independently predicted excessive daytime sleepiness. Medical/nursing personnel also reported higher rates of weight gain and greater daytime sleepiness compared with non-medical staff.

Conclusion: This study demonstrates that clinician-led sleep interviews can effectively identify key sleep phenotypes in healthcare professionals, revealing that evening-type individuals consistently exhibit a more favorable sleep profile. Targeted screening of resilient sleep phenotypes—such as the evening type identified in this study—can help support safer and more sustainable working conditions for healthcare professionals.

Keywords: Chronotype, daytime sleepiness, insomnia, occupational health, shift work, sleep quality

Corresponding author:
Katerina Vlami,
MD, MSc. MPH, ESRS Somnologist
*Occupational & Environmental Health, Dept Public Health Policy, School of Public Health, University of West Attica, Athens, Greece.
**2nd Pulmonary Department, School of Medicine, National and Kapodistrian University of Athens, "ATTIKON" University Hospital, Haidari, Athens, Greece.
Address: Rimini 1, str, Post Code 12462, Haidari, Athens, Greece.
Tel. number: +00306977564088
E-mail: kvlami1969@yahoo.gr
ORCID ID: https://orcid.org/0000-0001-5117-2257

Date of submission: 04.09.2025
Date of acceptance: 25.03.2026
Date of publication: 15.04.2026

Conflicts of interest: None
Supporting agencies: None
DOI:https://doi.org/10.3126/ijosh.v16i1.84103

Copyright: This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License

Introduction

Sleep and occupation are both foundational to human well-being,[1] yet work demands often interfere with adequate and restorative sleep. In today's society, which increasingly depends on 24/7 services, this conflict is more pronounced than ever.[2] Irregular work schedules are common among shift workers who may work early mornings, evenings, nights, or rotating shifts. These patterns disrupt natural circadian rhythms,[3] and are associated with a range of adverse outcomes including insomnia, fatigue, cardiometabolic disorders, depression, and even increased cancer risk.[4,5]

Globally, an estimated 15–25% of the workforce is engaged in shift work, and healthcare settings often rely on round-the-clock staffing[6]. Research indicates that between 50% and 89% of nurses perform some form of shift work monthly, often reporting worse sleep duration, quality, and increased daytime fatigue compared to those with fixed daytime schedules.[7,8] Compounding this, frequent transitions between day and night shifts further misalign circadian rhythms.

Chronotype, which is an individual's natural sleep-wake preference, is a key determinant of how well one tolerates shift work.[9,10] The interaction between work schedules and chronotypes can significantly influence sleep outcomes, cognitive function, and overall job performance.[11,12]

Despite the growing body of evidence on sleep disturbances among healthcare professionals, most studies rely solely on self-administered questionnaires. As a result, nuanced sleep phenotypes—particularly those shaped by a combination of personal, occupational, and biological factors—are often overlooked.

Therefore, our aim was to investigate sleep patterns of healthcare professionals at a large tertiary university hospital, using in-person interviews conducted by a certified sleep specialist, who administered validated sleep instruments such as PSQI,[13] AIS,[14,15] and ESS.[16-18]

Methods

This observational, cross-sectional study was conducted at a single large tertiary university hospital between December 2021 and February 2022. The target population comprised all hospital employees (clinical, technical, and administrative staff). The employee cohort at the time included approximately 600 staff members, from whom the study sample was drawn. The initial invitation was directed specifically to this subgroup. As an exploratory study designed to identify sleep-related phenotypes using in-depth interviews, our recruitment strategy prioritized feasibility and direct engagement over random sampling. A total of 115 hospital employees were informed about the study via institutional email from the sleep specialist (KV), who explained the objectives and procedures. The study followed a convenience sampling approach. Recruitment was conducted through walk-around visits during morning and early-afternoon hours—periods when most staff members are present. During these walk-arounds, KV visited clinical, technical, and administrative departments to explain the study procedures, answer questions, and invite employees to participate. Of these 55 employees expressed interest and underwent pre-screening. Of these, 42 met the inclusion criteria and were invited to participate. Thirty-eight employees, (90.5%) fully completed the required protocol, forming the final study sample. This corresponds to a participation rate of 33% based on the initially informed group and a high response rate of 90.5% among eligible individuals.

Employees who worked typical shifts (7:00 a.m.–3:00 p.m.) or non-regular rotating shift patterns (i.e., hours outside the conventional 7 a.m.–6 p.m. timeframe or involving rotation) were eligible. Participation in the study was voluntary. Exclusion criteria included temporary employees, a history of alcoholism, depression or anxiety disorders, use of medications that affect sleep, known malignancy, diagnosed sleep disorders and pregnancy.

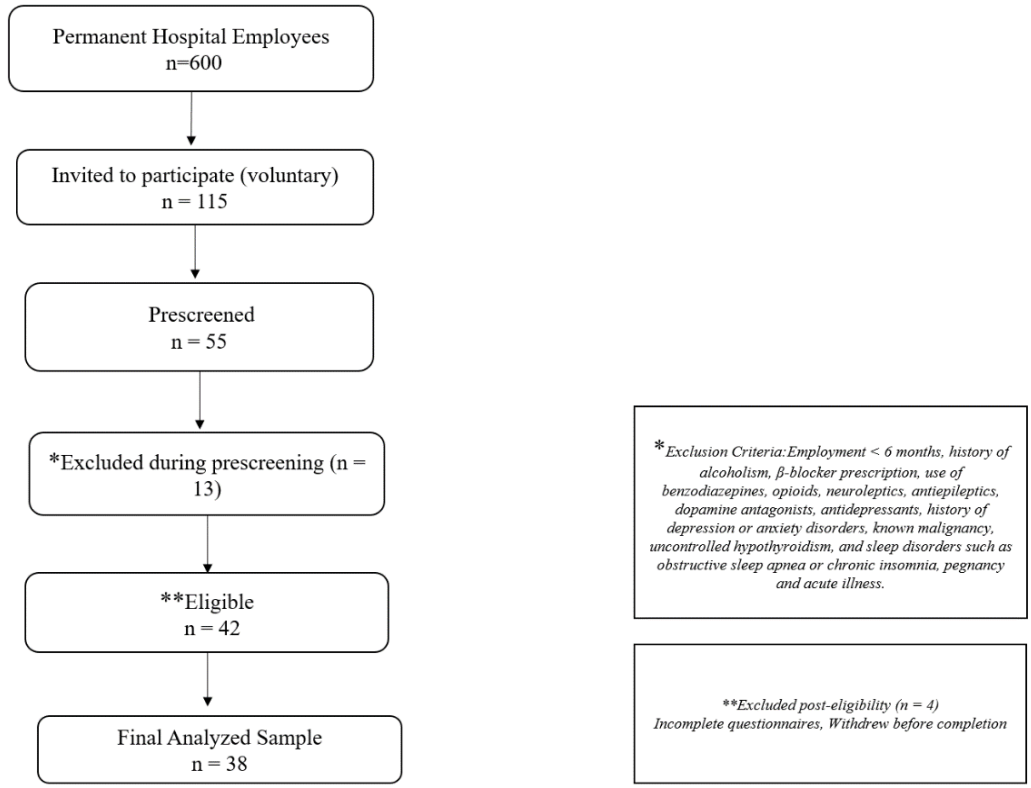


Figure 1: Participant flow according to STROBE guidelines.

Demographic data were collected. Occupational and cognitive variables were assessed using a structured set of interviewer-administered Yes/No questions. These included: work performance impairment: 'Did you have good job performance in the previous month?', perceived workload: 'Do you feel that your workload is excessive or unmanageable?', presenteeism: 'Have you worked while feeling unwell or unfit for work in the past month?', mental strain: 'Do you often feel mentally exhausted or overwhelmed during or after work?', concentration difficulties: 'Do you often have poor concentration during work?', memory problems: 'Do you often have disturbed memory?', morning headaches: 'Do you often wake up with a headache?'

Weight gain in our study was assessed using a single self-reported item 'Have you gained weight in the last six months?' coded Yes/No. All dichotomous variables (Yes/No responses) were coded binarily (0 = No, 1 = Yes).

Sleep and daytime sleepiness were assessed through three validated, Greek-translated, interviewer-administered questionnaires: the PSQI, the AIS, and the ESS. The PSQI is a self-rated 19-item questionnaire measuring sleep quantity and quality over the previous month. Scores range from 0 to 21, with higher scores indicating poorer sleep; scores $\geqslant 5$ indicate clinically significant sleep disturbances. The AIS includes 8 items reflecting ICD-10 insomnia criteria, scored on a 4-point Likert scale (total score: 0 – 24), with scores $\geqslant 6$ suggesting insomnia. The ESS assesses daytime sleepiness using 8 scenarios, each rated 0 – 3 (total score: 0 – 24); scores $\geqslant 10$ indicate excessive daytime sleepiness. The scoring procedures and diagnostic cut-offs for each questionnaire (PSQI $\geqslant 5$, AIS $\geqslant 6$, ESS $\geqslant 10$) were pre-specified based on their validated Greek versions and established clinical criteria. The questionnaires were administered via a structured interviewer-assisted format to ensure completeness and accuracy, a method consistent with their validated use in Greek clinical studies.

Chronotype was assessed using a single self-reported question about time-of-day preference, categorizing individuals as morning, evening, or neither type. This approach was selected to

minimize respondent burden and maintain feasibility within the interviewer-administered format of this exploratory study. For analysis, comparisons were made between evening types and non-evening types to reduce potential misclassification from the "neither type" category. All responses were binary-coded and used in univariate analyses to examine associations with PSQI, AIS, and ESS scores. Data were entered into Microsoft Excel and analyzed using STATA/IC 13.0 (Stata Corp, College Station, TX). Normality was assessed with the Kolmogorov–Smirnov test and, as distributions were non-normal, quantitative variables are reported as medians with interquartile ranges (IQRs), and categorical variables as frequencies and percentages. Group comparisons for PSQI, AIS, and ESS scores were performed using the Mann–Whitney U test, while categorical variables were examined using Chi-square tests; Fisher's exact test was applied when expected cell counts were <5. Multivariable logistic regression models were constructed to evaluate independent predictors of poor sleep quality, insomnia symptoms, and excessive daytime sleepiness. Statistical significance was set at $p \leqslant 0.05$. The study adhered to STROBE guidelines (Supplementary File 1).

Ethics Approval and Consent to Participate

The study protocol was approved by the Human Research Ethics Committee of the General University Hospital (ΒΠΝΕΥΜ, ΕΒΔ549/11-10-2021) and was conducted in accordance with the principles of the Declaration of Helsinki (2013 revision). All participants were enrolled voluntarily.

Results

Thirty-eight employees fully completed the required protocol, with 37% being men and a mean age of 44 ± 9.68. Participants' characteristics are shown in Table 1.

Table 1: Demographic and clinical characteristics of the participants (n = 38).

CHARACTERISTIC	VALUE
Gender, men, n (%)	14/38 (37%)
Age, (years) (mean ± sd)	44 ± 9.68
Self-perceived overweight, n (%)	18/38 (47%)
Smoking, n (%)	19/38 (50%)
Medical/nurse staff, n (%)	23/38 (60%)
Non-standard work schedule, n (%)	10/38 (26%)
Sleep duration, (hours/day) (mean ± sd)	6.31 ± 1.08
PSQI ≥ 5, n (%)	28/38 (74%)
AIS ≥ 6, n (%)	19/38 (50%)
ESS ≥ 10, n (%)	12/38 (32%)

Abbreviations: AIS: Athens Insomnia Scale (range 0–24); ESS: Epworth Sleepiness Scale (range 0–24); PSQI: Pittsburgh Sleep Quality Index (range 0–21)

Table 1 shows that a total of 38 healthcare professionals were included in the analysis. Most participants were medical or nursing staff (23/38; 60%), and 10/38 (26%) reported a non-standard or rotating shift schedule. Sleep duration was below the recommended minimum for the majority of participants, with 28/38 (74%) reporting <7 hours of sleep per night (mean 6.31 ± 1.08 hours). Poor sleep quality was common: 28/38 (74%) scored ⩾5 on the PSQI, while 19/38 (50%) scored ⩾6 on the AIS, indicating insomnia symptoms. Excessive daytime sleepiness (ESS ⩾ 10) was reported by 12/38 (32%).Table 2 summarizes the associations between sleep measures and occupational or individual characteristics. In this sample, poor sleepers

(PSQI ⩾ 5) were younger (p = 0.002) and showed higher insomnia and daytime sleepiness scores. Participants reporting poor job performance tended to show higher PSQI, AIS, and ESS scores compared with those without perceived impairment (PSQI: 10 [8–12] vs. 7 [4–8], p = 0.014; AIS: 8 [6–15] vs. 4 [1–8]; ESS: 10 [8–12] vs. 6.5 [3–9.5]). Evening-type individuals reported lower PSQI, AIS, and ESS scores (PSQI: 5.5 [3–9] vs. 8 [6.5–10], p = 0.043; AIS: 2.5 [1–6] vs. 8 [5–10.5], p = 0.002; ESS: 5.5 [1–8] vs. 9 [5.5–10], p = 0.015). Mental strain was significantly associated with insomnia severity (AIS 6.5 [3–9] vs. 1.5 [1–6.5]; p = 0.028), but not with PSQI or ESS. Poor concentration was associated with higher PSQI, AIS, and ESS scores (PSQI: 8 [7–10] vs. 6 [3–8], p = 0.014; AIS: 8 [5–10] vs. 3 [1–7], p = 0.007; ESS: 9 [7–11] vs. 5 [3–9], p = 0.030). Morning headaches also clustered with poorer sleep across all indices (PSQI: 9 [7.5–11.5] vs. 6 [4–8], p = 0.011; AIS: 10 [8.5–14.5] vs. 3 [1–7], p < 0.001; ESS: 11.5 [8.5–15] vs. 5.5 [3–9], p = 0.001). Increased weight was similarly associated with higher AIS (7 [3–10] vs. 2 [1–7.5], p = 0.008) and ESS (10 [5–11] vs. 5.5 [1.5–7.5], p = 0.003). In the multivariable logistic regression models adjusted for age, sex, profession, shift status, workload, presenteeism, and job performance, chronotype emerged as the only consistent independent predictor of sleep quality and insomnia, with evening-type individuals showing markedly lower odds of PSQI⩾5 (OR 0.09, p = 0.046) and AIS⩾6 (OR 0.17, p = 0.046) (Supplement file A). Conversely, reduced job performance independently predicted excessive daytime sleepiness (ESS⩾10; OR 0.06, p = 0.049) (Supplement file A).

Table 2: Comparison of sleep, cognition and occupational parameters of the employees according to PSQI, AIS and ESS (n=38)

Variable	Condition	PSQI (Median (IQR)	pa	AIS (Median (IQR)	pb	ESS (Median IQR)	pc
Age	<40	8 (8-11)	0.002	8 (3-8)	0.089	9 (6-10)	0.077
	≥40	6 (3-8)		3 (1-7)		5 (3-9)	
"Did you have good job performance in the previous month?"	No (poor performance)	10 (8-12)	0.014	8 (6-15)	0.067	10 (8-12)	0.066
	Yes (good performance)	7 (4-8)		4 (1-8)		6.5 (3-9.5)	
"Do you feel that your workload is excessive or unmanageable?"	No	5.5 (2-8)	0.375	3 (1-5)	0.432	7 (3-10)	0.967
	Yes	7.5 (5-9)		6 (1.5-8)		7 (4-10)	
"Have you worked while feeling unwell or unfit for work in the past month?"	No	8 (4-9.5)	0.720	5 (1-8)	0.326	6.5 (3-9.5)	0.187
	Yes	7 (6-8)		7 (6-8)		10 (7-11)	
"Are you an evening type?"	No	8 (6.5-10)	0.043	8 (5-10.5)	0.002	9 (5.5-10)	0.015
	Yes	5.5 (3-9)		2.5 (1-6)		5.5 (1-8)	

"Feeling mentally exhausted or overwhelmed during/after work?"	No	6 (2.5-9)	0.3676	1.5 (1-6.5)	0.028	6.5 (2.5-10)	0.613
	Yes	7.5 (5-9)		6.5 (3-9)		7 (5-10)	
"Do you often have disturbed memory?"	No	7.5 (4.5-8.5)	0.701	5 (1-8)	0.317	7 (3-9.5)	0.385
	Yes	7 (4-10)		6.5 (3-10)		9 (5-10)	
"Do you often have poor concentration during work?"	No	6 (3-8)	0.014	3 (1-7)	0.007	5 (3-9)	0.030
	Yes	8 (7-10)		8 (5-10)		9 (7-11)	
"Do you often wake up with a headache?"	No	6 (4-8)	0.011	3 (1-7)	0.000	5.5 (3-9)	0.001
	Yes	9 (7.5-11.5)		10 (8.5-14.5)		11.5 (8.5-15)	
Self-perceived overweight	No	7 (3.5-8.5)	0.331	2(1-7.5)	0.0082	5.5 (1.5-7.5)	0.003
	Yes	8 (5-10)		7(3-10)		10 (5-11)	

(YES = presence of symptom/condition; NO = absence) Abbreviations: AIS: Athens Insomnia Scale (range 0–24); ESS: Epworth Sleepiness Scale (range 0–24); IQR: interquartile range; PSQI: Pittsburgh Sleep Quality Index (range 0–21); p-value: pa based on PSQI; pb based on AIS; pc based on ESS. In bold are statistically significant results when $p < 0.05$.

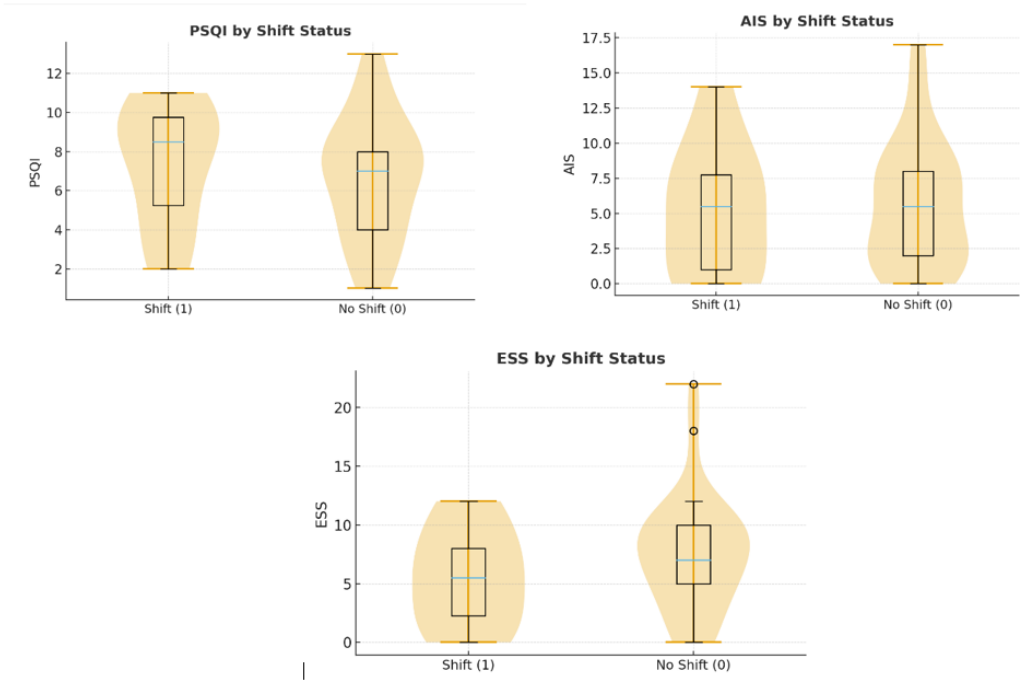
Table 3 presents a comparison of occupational, cognitive, and sleep parameters between medical-nurse staff and non-medical staff. Decreased job performance issues were more prevalent among the medical-nurse staff, with 6/23 (26%) reporting "No" compared to none in the non-medical staff group ($p = 0.031$). Weight gain was significantly higher in the medical-nurse group, with 14/23 (60.87%) reporting increased weight versus 4/15 (26.67%) in the non-medical group ($p = 0.039$). Additionally, daytime sleepiness, as measured by the ESS, was greater in the medical-nurse staff, with a median score of 9 (IQR: 3–10), compared to 5 (IQR: 2–7) in the non-medical group ($p = 0.036$), suggesting greater occupational and health challenges among the medical-nurse staff. When categorical comparisons were recalculated using Fisher's exact test to account for small cell counts, the previously observed association between professional group and self-reported job performance no longer reached statistical significance and instead showed a non-significant trend ($p = 0.063$). All other Fisher-adjusted comparisons remained significant (See Supplement file A). Violin plots demonstrated that medical–nursing staff exhibited a clear shift toward higher ESS scores compared with non-

medical staff, whereas the distributions of PSQI and AIS scores were broadly similar across professional groups. Likewise, no meaningful differences in PSQI, AIS, or ESS distributions were observed between shift-workers and non–shift-workers, supporting the absence of a shift-work effect in our cohort (Figure 2).

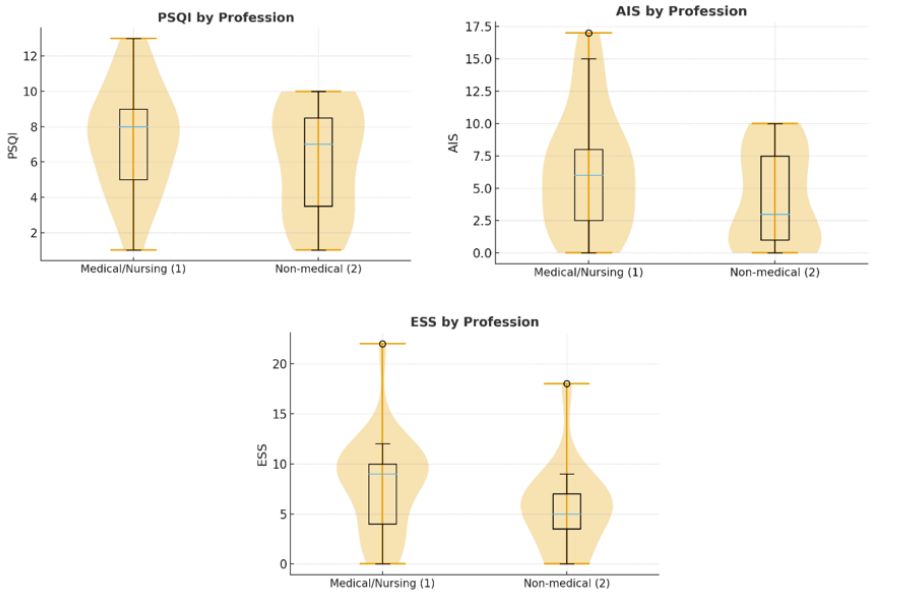
Table 3: Comparison of sleep, cognition and occupational parameters of medical-nurse and non medical staff n=38

Parameters		**Medical-Nurse staff**	**Non Medical-Nurse staff**	**p-value**
"Did you have good job performance in the previous month?" (n, %)	No	6/23 (26%)	0 (0%)	**0.031**
	Yes	17/23 (73.91%)	15/15 (100%)	
"Do you feel that your workload is excessive or unmanageable?" (n, %)	No	3/23 (13.04%)	3/15 (20%)	0.565
	Yes	20/23 (86.96%)	12/15 (80%)	
"Have you worked while feeling unwell or unfit for work in the past month?" (n, %)	No	22/23 (95.65%)	15/15 (100%)	0.314
	Yes	1/23 (4.35%)	0 (0%)	
"Are you an Evening Type? " (n, %)	No	12/23 (52.17%)	4/15 (26.67 %)	0.428
	Yes	11/23 (47.83%)	11/15 (73.33%)	
"Feeling mentally exhausted or overwhelmed during/after work?" (n, %)	No	7/23 (30.43%)	5/15 (33.33%)	0.851
	Yes	16/23 (69.57%)	10/15 (66.6%)	
"Do you often have disturbed memory?" (n, %)	No	16/23 (69.57%)	12/15 (80%)	0.475
	Yes	7/23 (30.43%)	3/15 (20%)	
"Do you often have poor concentration during work?" (n, %)	No	13/23 (56.52%)	10/15 (66.67%)	0.532
	Yes	10/23 (43.48%)	5/15 (33.33%)	
"Do you often wake up with a headache?" (n, %)	No	17/23 (73.91%)	13/15 (86.67%)	0.346
	Yes	6/23 (26.09%)	2/15 (13.33%)	
Self-perceived overweight (n, %)	No	9/23 (39.13%)	11/15 (73.33%)	**0.039**
	Yes	14/23 (60.87%)	4/15 (26.67%)	
PSQI (Median, IQR)		8 (5-9)	7 (3-9)	0.285
AIS (Median, IQR)		6 (2-8)	3 (1-8)	0.158
ESS (Median, IQR)		9 (3-10)	5 (2-7)	**0.036**

(Yes = presence of symptom/condition; No = absence)



Violin plots with embedded boxplots illustrate the distribution and central tendency of PSQI, AIS, and ESS scores by shift work.



Violin plots with embedded boxplots illustrate the distribution and central tendency of PSQI, AIS, and ESS scores by profession.

Figure 2: Violin plots with embedded boxplots illustrate the distribution and central tendency of PSQI, AIS, and ESS scores by profession and shift work

Discussion

This exploratory study shows that combining in-person interviews conducted by a certified sleep specialist with validated sleep instruments (PSQI, AIS, ESS) effectively characterizes sleep patterns and delineates sleep phenotypes among healthcare professionals in a large tertiary university hospital. A substantial proportion of participants reported poor sleep quality, short sleep duration, and frequent symptoms of insomnia and daytime sleepiness.

Interestingly, in this study, chronotype emerged as the clearest individual characteristic linked to

sleep outcomes, with evening-type participants showing markedly lower odds of both poor sleep quality and insomnia symptoms even after adjustment for demographic and occupational factors. In contrast, job performance was the only variable that demonstrated an independent association with daytime sleepiness. Additionally, medical/nursing staff showed higher levels of self-perceived overweight and daytime sleepiness compared with non-medical staff. Although younger participants initially showed poorer sleep quality on the PSQI—mirroring prior findings that younger employees often experience greater insomnia symptoms and daytime sleepiness due to circadian misalignment, social jetlag, and lifestyle pressures—these age-related differences were no longer significant after adjusting for key demographic and occupational factors, indicating that age itself was not an independent predictor of sleep outcomes.[19] This suggests that the vulnerability of younger workers observed in unadjusted data may largely reflect underlying circadian preference rather than chronological age per se.[20] This interpretation aligns with broader evidence showing that younger adults are more often evening types and more prone to behaviors that exacerbate circadian misalignment and sleep restriction.[21]

In our cohort, evening-type workers demonstrated better sleep quality and fewer insomnia symptoms, and chronotype emerged as the only independent predictor of both outcomes. Although eveningness is often associated with poorer mental health and increased vulnerability to shift-work–related strain in larger epidemiological studies,[22] our findings are consistent with research showing that when work demands align more closely with an individual's circadian preference, sleep outcomes may transiently improve.[23,24] Importantly, most participants in this study were over 40 years old, an age group in which evening preference is typically less pronounced physiologically. This suggests that the evening types in our sample may represent individuals whose circadian preference is either stable and biologically rooted, or who have adapted over years of professional exposure to rotating or late schedules, potentially mitigating sleep disruption.[25] Longitudinal evidence in newly hired nurses indicates that chronotype before shift-work exposure predicts later resilience trajectories: morning types maintain stable resilience, whereas intermediate and evening types show declines in resilience and worsening sleep over time, with resilience mediating these effects.[26] Such findings imply that eveningness may be advantageous in the short term when schedules are compatible with circadian preference, but may confer long-term vulnerability under sustained misalignment. Within this framework, the better sleep outcomes observed in evening-type staff in our sample may reflect a selection or adaptation effect, whereby individuals with an evening orientation are better able to cope with irregular or late hospital schedules, at least at present. Nevertheless, despite the more favorable sleep profile observed among evening-type employees, no corresponding advantage was detected in self-reported job performance. This discrepancy likely reflects the multifactorial nature of occupational functioning, in which sleep interacts with workload intensity, organizational culture, role-specific demands, and individual coping strategies.[27] According to the literature, research on chronotype and workplace performance similarly reports mixed findings: some studies suggest that evening types tolerate night work better, whereas others show no consistent advantage and, in some cases, poorer overall work ability relative to morning types.[28] Although evening-type individuals may experience fewer sleep complaints due to alignment with late-night schedules, they are at a disadvantage in healthcare environments that rely heavily on early-morning activity and tightly structured daytime routines.[29] Any misalignment between circadian biology and job requirements can impair alertness, psychomotor function, and productivity, highlighting the complex interplay between chronotype and

occupational scheduling.[30,31,32] Additionally, evidence from Crowley et al. shows that even when circadian alignment improves, as occurred during COVID-19 lockdowns, individuals with stronger evening tendencies may experience reduced work engagement, despite reporting longer sleep duration, reduced social jetlag, and better synchronization between biological and social time.[33] These results suggest that eveningness may carry inherent vulnerabilities for cognitive, motivational, or attentional performance, independent of sleep quality itself.[34] Moreover, evening types often experience poorer daytime alertness, reduced morning cognitive efficiency, and less optimal alignment with early-day task demands, factors that may persist even when sleep health is improved. Thus, our finding of diminished job performance among evening-type staff—despite their better sleep quality—may reflect a broader pattern in which evening chronotype supports sleep continuity but does not confer advantages for work performance, particularly in professions that demand sustained vigilance, early-day functioning, or high emotional and cognitive engagement. Moreover, poor job performance itself emerged as a strong independent predictor of higher daytime sleepiness (ESS $\geqslant$ 10). This aligns with conceptual models suggesting that decrements in work performance — whether subjective or objective—may signal underlying fatigue, reduced alertness, or cognitive inefficiency, which subsequently manifest as excessive daytime sleepiness.[35]

Finally, medical and nursing staff in our sample reported greater weight gain and higher daytime sleepiness than their non-medical counterparts. The distributional patterns of PSQI and AIS scores were broadly similar across professional groups, and no meaningful differences in any sleep measure were observed between shift-workers and non–shift-workers, indicating that shift schedule alone did not account for sleep outcomes in this cohort. Instead, the most prominent difference concerned daytime sleepiness, which was markedly higher among medical–nursing staff. This dissociation suggests that excessive daytime sleepiness in frontline healthcare workers may arise from factors beyond nocturnal sleep disturbances—such as cognitive overload, emotional strain, high work intensity, or chronic effort–reward imbalance—all of which can impair alertness even when sleep quality appears relatively preserved.[36] The significantly higher prevalence of overweight/obesity among medical–nursing staff may further contribute to elevated sleepiness through metabolic and inflammatory pathways, independent of sleep-disordered breathing, which was excluded by design. Although our sample size did not permit formal mediation analysis, excess weight remains a plausible contributor. Given the cross-sectional nature of the study, these associations must be interpreted cautiously: weight gain and daytime sleepiness may influence one another bidirectionally, and both may be shaped by unmeasured factors such as workload intensity, psychosocial stress, or compensatory caffeine use. Overall, our findings suggest that daytime sleepiness in this occupational group is more likely to arise from a multifactorial interplay of metabolic burden and occupational stressors rather than from impaired sleep per se. Prior literature supports a bidirectional relationship between obesity and sleep-related symptoms, whereby insufficient sleep can worsen insulin resistance and disrupt ghrelin–leptin regulation, increasing appetite and weight gain, while excess weight can independently contribute to fatigue and daytime sleepiness.[37] These patterns may be amplified in clinical roles that involve heavier workloads, high emotional demands, and greater exposure to circadian strain, underscoring the need for targeted strategies to protect the health and performance of healthcare personnel.[38, 39]

The strengths of this study include the use of specialist-led, face-to-face sleep interviews, which enhanced the accuracy and interpretability of questionnaire responses. Combining clinical interviewing with validated

sleep measures (PSQI, AIS, ESS) enabled a more nuanced characterization of sleep patterns than would be achievable using self-administered surveys alone. Nonetheless, several limitations warrant consideration. Participation was voluntary, raising the possibility of self-selection bias, although proactive walk-arounds across departments helped mitigate this risk. Several constructs—including chronotype—were assessed using single-item measures rather than full validated questionnaires, reflecting the practical constraints of a structured interview design. The small sample size restricted the power to detect subtle associations, limited multivariable modeling, and reduces generalizability. In addition, the single-site design and underrepresentation of permanent night-shift workers—likely due to morning recruitment—further limit applicability. As an exploratory study aimed at identifying sleep-related phenotypes, feasibility and direct engagement were prioritized over random sampling; however, larger stratified studies are needed to validate and extend these findings.

Conclusion

This study underscores the clear diagnostic value of personal, clinician-led interviews in revealing how demographic, cognitive, and occupational factors interact to drive sleep disturbances in healthcare professionals (Figure 3). High-risk profiles—particularly younger staff and those with an evening-type circadian rhythm—exhibit a multifaceted, sleep-deficit phenotype that undermines both professional performance and personal well-being. Integrating face-to-face interviews by trained sleep specialists into occupational health programs can enhance early detection and more precise characterization of sleep problems. Such integration should inform targeted interventions to improve staff well-being—an essential prerequisite for safeguarding clinicians' health and maintaining the quality and safety of patient care. Addressing these issues is vital, as the strengthening of hospital occupational health and safety services has been shown to be a critical factor in preventing workplace accidents and occupational hazards, particularly in the demanding environment of healthcare settings.[39,40]

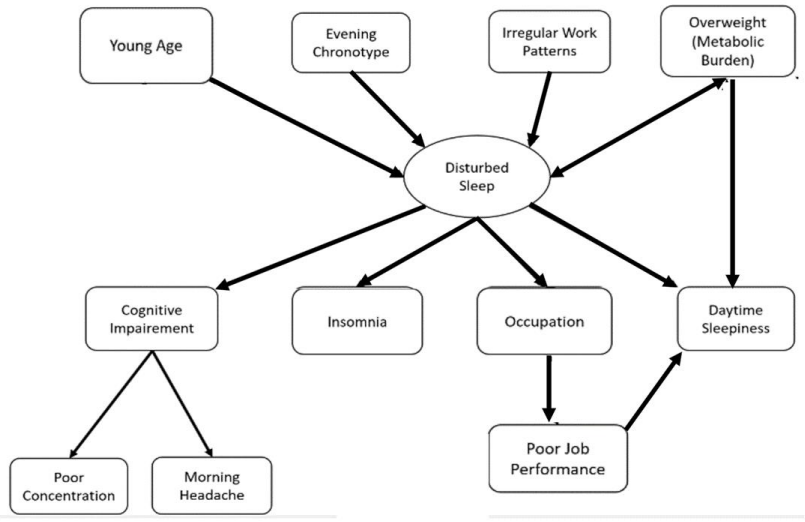


Figure 3: The multifaceted phenotype of healthcare professionals: Sleep Disturbance defines the Multifaceted Phenotype of Healthcare Professionals

Acknowledgements

The authors thank the staff of the General University Hospital for their participation in this study.

References

1. Ross CE, Mirowsky J. Does employment affect health? J Health Soc Behav. 1995;36(3):230–43:7594356. Available from: https://pubmed.ncbi.nlm.nih.gov/7594356/
2. Knudsen HK, Ducharme LJ, Roman PM. Job stress and poor sleep quality: data from an American sample of full-time workers. Soc Sci Med. 2007;64(10):1997–2007. Available from: https://doi.org/10.1016/j.socscimed.2007.02.020
3. Åkerstedt T. Shift work and disturbed sleep/wakefulness. Occup Med (Lond). 2003;53(2):89–94. Available from: https://doi.org/10.1093/occmed/kqg046
4. Cappuccio FP, Miller MA. Sleep and cardio-metabolic disease. Curr Cardiol Rep. 2017;19(11):110. Available from: https://doi.org/10.1007/s11886-017-0916-0
5. Mogavero MP, DelRosso LM, Fanfulla F, Bruni O, Ferri R. Sleep disorders and cancer: state of the art and future perspectives. Sleep Med Rev. 2021;56:101409. Available from: https://doi.org/10.1016/j.smrv.2020.101409
6. Almeida CM, Malheiro A. Sleep, immunity and shift workers: a review. Sleep Sci. 2016;9(3):164–8. Available from: https://doi.org/10.1016/j.slsci.2016.10.007
7. Rosa D, Terzoni S, Dellafiore F, Destrebecq A. Systematic review of shift work and nurses' health. Occup Med (Lond). 2019;69(4):237–43. Available from: https://doi.org/10.1093/occmed/kqz063
8. Karhula K, Härmä M, Sallinen M, Hublin C, Virkkala J, Kivimäki M, et al. Job strain, sleep and alertness in shift working health care professionals. Ind Health. 2013;51(4):406–16. Available from: https://doi.org/10.2486/indhealth.2013-0015
9. Arendt J. Shift work: coping with the biological clock. Occup Med (Lond). 2010;60(1):10–20. Available from: https://doi.org/10.1093/occmed/kqp162
10. Montaruli A, Castelli L, Mulè A, Scurati R, Esposito F, Galasso L, et al. Biological rhythm and chronotype: new perspectives in health. Biomolecules. 2021;11(4):487. Available from: https://doi.org/10.3390/biom11040487
11. Van Dongen HP. Shift work and inter-individual differences in sleep and sleepiness. Chronobiol Int. 2006;23(6):1139–47. Available from: https://doi.org/10.1080/07420520601100971
12. Gaba DM, Howard SK. Patient safety: fatigue among clinicians and the safety of patients. N Engl J Med. 2002;347(16):1249–55. Available from: https://doi.org/10.1056/NEJMsa020846
13. Buysse DJ, Reynolds CF III, Monk TH, Berman SR, Kupfer DJ. The Pittsburgh Sleep Quality Index: a new instrument for psychiatric practice and research. Psychiatry Res. 1989;28(2):193–213. Available from: https://doi.org/10.1016/0165-1781(89)90047-4
14. Soldatos CR, Dikeos DG, Paparrigopoulos TJ. Athens Insomnia Scale: validation of an instrument based on ICD-10 criteria. J Psychosom Res. 2000;48(6):555–60. Available from: https://doi.org/10.1016/S0022-3999(00)00095-7
15. Soldatos CR, Dikeos DG, Paparrigopoulos TJ. The diagnostic validity of the Athens Insomnia Scale. J Psychosom Res. 2003;55(3):263–7. Available from: https://doi.org/10.1016/S0022-3999(02)00604-9
16. Johns MW. Daytime sleepiness, snoring, and obstructive sleep apnea: the Epworth Sleepiness Scale. Chest. 1993;103(1):30–6. Available from: https://doi.org/10.1378/chest.103.1.30
17. Perantoni E, Steiropoulos P, Siopi D, Amfilochiou A, Michailidis V, Christoforatou K, et al. Validation of the Greek version of Pittsburgh Sleep Quality Questionnaire in a sleep lab population. Eur Respir J. 2012;40(56):903. Available from: https://doi.org/10.1378/chest.103.1.30
18. Tsara V, Serasli E, Amfilochiou A, Constantinidis T, Christaki P. Greek version of the Epworth Sleepiness Scale. Sleep Breath. 2004;8(2):91–5. Available from: https://doi.org/10.1007/s11325-004-0091-6
19. Zeitzer JM, Duffy JF, Lockley SW, Dijk DJ, Czeisler CA. Plasma melatonin rhythms in young and older

humans during sleep, sleep deprivation, and wake. Sleep. 2007;30(11):1437–43. Available from: https://doi.org/10.1093/sleep/30.11.1437

20. Huang YL, Liu RY, Wang QS, Van Someren EJ, Xu H, Zhou JN. Age-associated differences in circadian sleep–wake and rest–activity rhythms. Physiol Behav. 2002;76(4–5):597–603. Available from: https://doi.org/10.1016/S0031-9384(02)00733-3

21. Costa G, Sartori S. Ageing, working hours and work ability. Ergonomics. 2007;50(11):1914–30. Available from: https://doi.org/10.1080/00140130701676054

22. Yang H, Kim S, Yoo SH, Mun Y, Choi ML, Lee JA, Song E. Sleep quality according to chronotype in nurses working 8-hour shifts. Occup Med (Lond). 2024;74(4):290–6. Available from: https://doi.org/10.1093/occmed/kqae029

23. Juda M, Vetter C, Roenneberg T. Chronotype modulates sleep duration, sleep quality, and social jet lag in shift-workers. J Biol Rhythms. 2013;28(2):141-51. Available from: https://doi.org/10.1177/0748730412475042

24. Vetter C, Fischer D, Matera JL, Roenneberg T. Aligning work and circadian time in shift workers improves sleep and reduces circadian disruption. Curr Biol. 2015;25(7):907–11. Available from: https://doi.org/10.1016/j.cub.2015.01.064

25. Chauhan S, Norbury R, Faßbender KC, Ettinger U, Kumari V. Beyond sleep: A multidimensional model of chronotype. Neurosci Biobehav Rev. 2023;148:105114. Available from: https://doi.org/10.1016/j.neubiorev.2023.105114

26. Park G, Park WJ, Kang KW, Kim H. Chronotype prior to shift work influences outcomes: resilience as a mediator of sleep and mental health. Sleep. 2025;48(11):zsaf180. Available from: https://doi.org/10.1093/sleep/zsaf180

27. Kowalczuk K, Krajewska-Kułak E, Sobolewski M. Relationships between sleep problems and stress coping strategies among nurses including socio-occupational factors. Front Psychiatry. 2021;12:660776. Available from: https://doi.org/10.3389/fpsyt.2021.660776

28. Lipnevich AA, Credè M, Hahn E, Spinath FM, Roberts RD, Preckel F. How distinctive are morningness–eveningness and the Big Five: a meta-analysis. J Pers Soc Psychol. 2017;112(3):491–509. Available from: https://doi.org/10.1037/pspp0000099

29. Boersma GJ, Mijnster T, Vantyghem P, Kerkhof GA, Lancel M. Shift work is associated with extensively disordered sleep, especially when working nights. Front Psychiatry. 2023;14:1233640. Available from: https://doi.org/10.3389/fpsyt.2023.1233640

30. Enright T, Refinetti R. Chronotype, class times, and academic achievement in university students. Chronobiol Int. 2017;34(4):445–50. Available from: https://doi.org/10.1080/07420528.2017.1281287

31. Chellappa SL, Morris CJ, Scheer FAJL. Daily circadian misalignment impairs human cognitive performance. Sci Rep. 2018;8:3041. Available from: https://doi.org/10.1038/s41598-018-20707-4

32. Peng J, Zhang J, Wang B, He Y, Lin Q, Fang P, et al. The relationship between sleep quality and occupational well-being: the mediating role of occupational self-efficacy. Front Psychol. 2023;14:1071232. Available from: https://doi.org/10.3389/fpsyg.2023.1071232

33. Crowley R, Javadi AH, Tamminen J. Better alignment between circadian preference and sleep and work timings during COVID-19 did not benefit work engagement at home. Chronobiol Int. 2023;40(10):1361–74. Available from: https://doi.org/10.1080/07420528.2023.2258954

34. Li B, Liao G, Lee PMY, Huss A, Ma YTJ, Chan JW, Wing YK, Tse LA. Association between matched chronotype and poor mental health among shift workers: a systematic review and meta-analysis. J Epidemiol Community Health. 2023;77(8):485–93. Available from: https://doi.org/10.1136/jech-2022-220280

35. Singh G, Viramgami A, Makwana B, Mishra S, Padhariya T, Dave V, Soundararajan S. Effort-reward imbalance, subjective sleep quality, and inflammation in female nurses at a tertiary hospital: a pilot study. Sci Rep. 2025;15(1):31650. Available from: https://doi.org/10.1038/s41598-025-17717-4

36. Caruso CC. Negative impacts of shift work and long work hours. Rehabil Nurs. 2014;39(1):16–25. Available from: https://doi.org/10.1002/rnj.107

37. Mosavat M, Mirsanjari M, Arabiat D, Smyth A, Whitehead L. The role of sleep curtailment on leptin levels in obesity and diabetes. Obes Facts. 2021;14(2):214–21. Available from: https://doi.org/10.1159/000514095

38. Booker LA, Magee M, Rajaratnam SMW, Sletten TL, Howard ME. Individual vulnerability to insomnia, excessive sleepiness and shift work disorder among healthcare shift workers: a systematic review. Sleep Med Rev. 2018;41:220–33. Available from: https://doi.org/10.1016/j.smrv.2018.03.005

39. Farantos G, Christofilea O, Dounias G. Hospital occupational health and safety services and accidents in Greek hospitals: a case study in a Greek health region. Multidisciplinary Reviews. 2026;9(3):e2026119. Available from: https://doi.org/10.31893/multirev.2026119

40. Mahato PK, Gautam B, Joshi SK. Occupational injuries sustained by caregivers in geriatric care homes of Kathmandu valley. Int J Occup Saf Health. 2019;9(1):3–7. Available from: https://doi.org/10.3126/ijosh.v9i1.25160

International Journal of Occupational Safety and Health

ISSN: 2091-0878 (Online) ISSN: 2738-9707 (Print)

Original Article

Study of the correlation between indoor air quality in school buildings and children's health problems in Greece

Bikaki M.A[1], Evrenoglou L[1], Dounias G[1], Cavoura O[1], Farantos G[1], Damikouka I[1]

[1]Department of Public Health Policy, School of Public Health, University of West Attica, Greece

Corresponding author:

Maria Anna Bikaki,
Public Health Inspector-Economist, MSc., PhDc, Department of Public Health Policy, School of Public Health, University of West Attica, Greece
E-mail: mbikaki@uniwa.gr
Tel.: +306977824227
ORCID ID: https://orcid.org/0009-0009-0829-3390

Date of submission: 30.11.2025
Date of acceptance: 04.03.2026
Date of publication: 15.04.2026

Conflicts of interest: The authors reported no conflict of interest.
Supporting agencies: The authors did not obtain any funding for this research.

DOI: https://doi.org/10.3126/ijosh.v16i1.86986

Copyright: This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License

ABSTRACT

Introduction: In recent years, air quality studies have focused on the indoor environments of school buildings, since children spend much of their daily time in the classrooms. Evidence indicates that indoor air pollutants can cause health problems to the vulnerable school population. The purpose of this study was to examine the correlation between air quality in school classrooms and students' health.

Methods: The study was conducted in sixty-one (61) classrooms of thirty-three (33) school buildings located in Central Athens within the Attica Region and in the Argolida Sector of the Peloponnese Region in Greece. Students' health in the selected school classrooms was evaluated using anonymous questionnaires completed by the students' parents. Indoor concentrations of chemical air pollutants in the selected classrooms such as carbon dioxide (CO_2), carbon monoxide (CO), volatile organic compounds (VOCs), nitrogen dioxide (NO_2), particulate matters (PM_{10}, $PM_{2.5}$), along with temperature (T) and relative humidity (RH), were monitored using the series 500 Portable Air Quality Monitor and used for statistical correlation analysis.

Results: The study showed that there was a statistically significant correlation between indoor CO_2 *(p=0.007)* and students' performance, indoor VOCs *(p=0.023)*, $PM_{2.5}$ *(p=0.008)* and bronchitis, indoor $PM_{2.5}$ *(p=0.002)* and asthma, indoor PM_{10} *(p=0.002)*, $PM_{2.5}$ *(p=0.012)* and migraines in students.

Conclusion: Indoor air pollution was related to students' health problems. Indoor air quality in school buildings is a critical environmental issue, and authorities must implement health policy strategies to minimize air pollutant concentrations in classrooms and protect student health.

Keywords: Health problems, Indoor air pollution, Public health, School children

Introduction

Epidemiological research indicates that indoor air quality is very important and can affect human health, as people spend approximately 90% of their time at home, at school or in educational buildings, or in the workplace.[1]

Outdoor air, building materials, equipment, and human activities may contribute to high indoor air pollution.[2] Over the last decade, studies have focused more on indoor environments because of the harmful effects on human health.[3]

Harmful air pollutants inside buildings include carbon dioxide (CO_2), carbon monoxide (CO), volatile organic compounds (VOCs), nitrogen dioxide (NO_2), particulate matter (PM_{10}, $PM_{2.5}$), and others.[4] It has been reported that the degradation of indoor air quality in buildings can negatively affect human health by causing a wide range of diseases.[5-6] Indoor air quality in schools is critical because students are vulnerable and sensitive to air pollutants. For this reason, monitoring air quality in classrooms within school buildings is essential for protecting public health.[7]

Very few studies have been conducted in recent years regarding indoor air quality in school buildings, especially since the outbreak of the COVID-19 pandemic. The aims of this study were: a) to record the health problems of school children in classrooms of selected schools in the Central Sector of Athens within the Attica Region and in the Argolida Sector of the Peloponnese Region in Greece, b) to investigate the correlations between indoor air quality in school buildings and students' health problems. The findings of this study can help authorities address the critical issue of indoor air quality in school buildings and implement measures to improve student health and protect this vulnerable population.

Methods

The epidemiological environmental survey was carried out as a cross-sectional study from March 2022 to May 2023 in sixty-one (61) classrooms of thirty-three (33) school buildings located in the Central Sector of Athens within the Region of Attica and in the Argolida Sector within the Peloponnese Region in Greece. Some windows and doors were opened during the survey to optimize ventilation, in line with COVID-19 recommendations.

The school visits were conducted after approval was granted by the Research Ethics Committee of the University of West Attica (No. 91717/22-10-2021) and the Ministry of Education and Religion of Greece (No. 156846/2-12-2021, 48986/3-5-2022, 26884/9-3-2023). Air quality sampling was conducted in 1 to 3 classrooms per school during a single day, from 08:00 to 15:00. Air pollutants such as CO_2, CO, VOCs, NO_2, PM_{10}, $PM_{2.5}$, along with T and RH, were monitored at 1-minute intervals during one teaching hour per classroom using the series 500 Portable Air Quality Monitor (AeroQual), which enables by the calibrated sensors a real-time surveying of common air pollutants.

Health data regarding school-aged students were obtained using anonymous questionnaires completed at home by the students' parents. Specifically, the first author distributed 1,003 questionnaires in sealed envelopes to students for delivery to their parents. Afterward, they were returned to the school's Principal in sealed envelopes. The final step of the procedure was for the school Principal to return the completed questionnaires for each classroom to the first author.

The questionnaire comprised fifty-one (51) questions consisting of the following parts: a) demographic data (age, gender etc.) b) nutrition habits, c) child's health status and health problems such as hypertension, cardiovascular diseases, respiratory diseases including asthma and allergies, neurological disorders, migraines, sleep disorders, depression, skin irritations, children's performance and behavior, etc.) and d) data about socioeconomic status, attitude and parents' habits. The questionnaires were accompanied by a consent form for the parents.

Statistical correlations were conducted between the air pollutant concentrations recorded by the AeroQual series 500 Portable Air Quality Monitor inside selected classrooms and student health data to evaluate the relationship between indoor pollutants and students' health problems.

Statistical analysis was conducted using IBM SPSS Statistics (SPSS) for Windows, version 29.0.1.0. and MS Excel 2007. Data were validated for normality. Chi-squared test, Pearson's correlation coefficient, and cross-tabulation were used as statistical methods. Results were also validated using the nonparametric Mann-Whitney U test. The statistical significance level was set at 5% ($\alpha = 0.05$).

Results

Of the 1.003 questionnaires distributed, 503 were completed by students' parents/guardians (response rate: 50.14%) and returned in sealed envelopes to the first author. The completed questionnaires concerned 264 male and 239 female students (Figure 1). In addition, 363 children resided in and attended school in the area of Central Athens, while 140 resided in the area of Argolida. The ages of schoolchildren are summarized in Table 1. The majority of the children in the survey were 12 years old (23.5%).

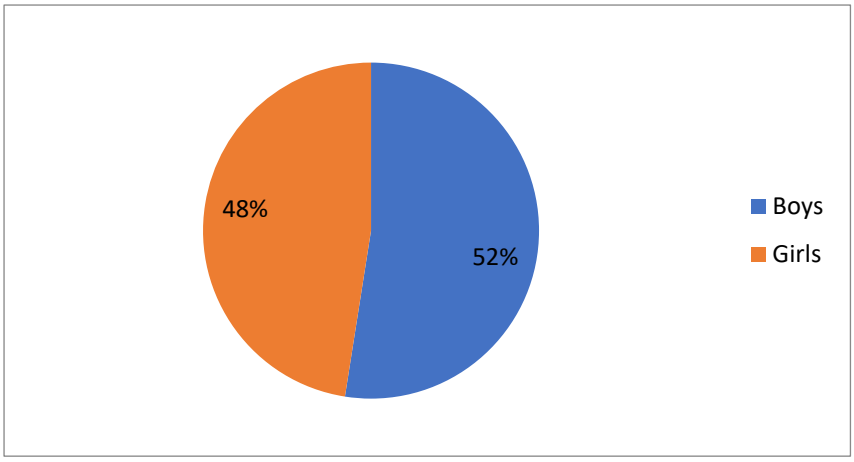


Figure 1: Students' sex in completed questionnaires

Table 1: Students' age in completed questionnaires

Age (years old)	Frequency (N)	%
7	52	10.3%
8	89	17.7%
9	16	3.2%
10	51	10.1%
11	112	22.3%
12	118	23.5%
13	33	6.6%
14	10	2.0%
15	22	4.4%

Most parents who completed the questionnaires had finished tertiary education (67.3%), 23.8% perceived indoor air of school buildings to be polluted, and 51.7% considered atmospheric pollution a major problem worldwide.

Statistical analysis of the questionnaires showed the following results regarding the health status and health problems of schoolchildren in the Central Athens and Argolida areas (Figure 2 and Table 2).

In Central Athens, within the Attica Region, 0.3% of students had hypertension, while no students had hypertension (0%) in the Argolida area within the Peloponnese Region.

Regarding the questionnaire results, 12.4% of students in the Athens area had allergies, while the percentage was lower in Argolida (2.9%).

Schoolchildren experienced bronchitis at a rate of 1.9%, while asthma at 3% in the Athens area. In the Argolida area, no cases of bronchitis or asthma were recorded among children.

23.4% of children in the school population in the Attica Region had difficulty concentrating, while 20.6% exhibited nervousness and hyperactivity. In contrast, children in the Argolida Region showed lower rates, with 8.6% of children experiencing concentration difficulties and 17.9% exhibiting nervousness and hyperactivity.

Regarding student performance, a decline was observed among 0.8% of students in the Attica Region, whereas no such deterioration was recorded in the Argolida Region. Student performance remained unchanged for 12.5% of the student population in the Attica Region, compared to 7.1% in the Argolida Region. Student performance improved for 86.7% of students in Central Athens, while a higher improvement rate of 92.9% was observed in the Argolida area. In the Attica Region, 1.4% of children exhibited neurological symptoms, such as convulsions (0.6%) and speech disorders (0.6%), while in the Argolida Region, no neurological symptoms were observed (0%) among children in the school population. 5% of children in the Athens area experienced migraines, compared to a significantly low rate of 0.7% in the Argolida area. 1.7% of the school population in the Central Sector of Athens showed symptoms of depression, while no children with symptoms of depression appeared in the Argolida Sector, according to the completed questionnaires. Sleep disorders were experienced by 0.8% of children in the school population in the Attica Region, whereas none were observed in the Peloponnese Region (0%). 10.7% of school children in the Attica Region had skin irritation, while in the Peloponnese Region the figure was 8.6%. The school children in both the Attica Region and the Peloponnese Region did not exhibit (0%) cardiovascular diseases or kidney problems, according to the completed questionnaires.

The correlation between students' health problems and concentrations of indoor air pollutants in classrooms where the cases occurred is shown in Table 3.

In the classrooms where children with allergy problems were present, the mean concentrations of indoor air pollutants were: 0.19 ppm CO, 792.93 ppm CO_2, 0.009 ppm NO_2, 11.84 ppm VOCs, 32.44 μg/m3 PM10, and 14.48 μg/m^3 $PM_{2.5}$. There was not a statistically significant correlation between indoor CO ($p=0.426$), CO_2 ($p=0.451$), NO_2 ($p=0.224$), VOCs (p=0.739), PM_{10} (p=0.270), $PM_{2.5}$ (p=0.756) and allergies in students.

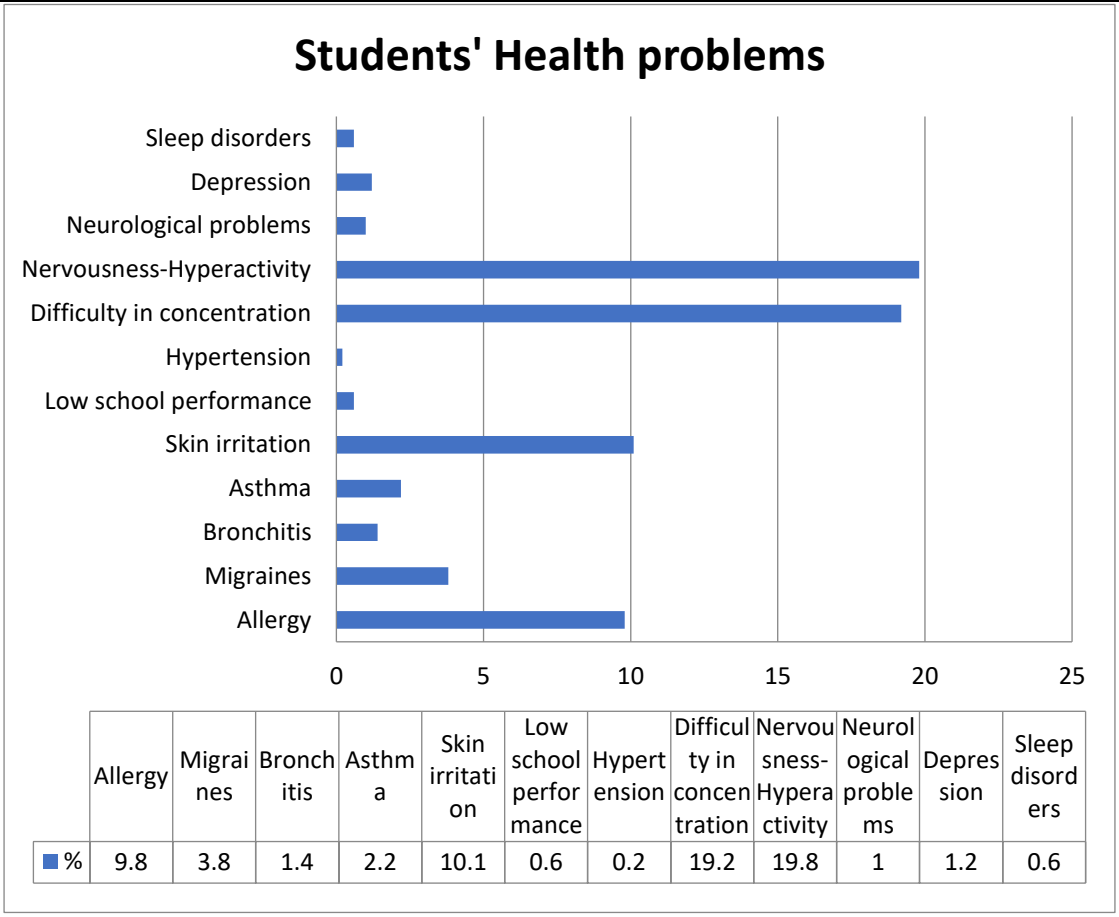


Figure 2: Reported health problems among students in the areas of Central Athens and in the Argolida

Table 2: Comparison of students' health problems between the area of Central Athens and the Argolida area

Students' Health problems	**Central Athens (N)**	**Argolida (N)**
Hypertension	1	0
Allergy	45	4
Bronchitis	7	0
Asthma	11	0
Difficulty in concentrating	84	12
Nervousness-hyperactivity	74	25
Problems with school performance	3	0
Neurological problems	5	0
Migraines	18	1
Depression	6	0
Sleep disorders	3	0
Skin irritation	39	12

Notes: *N= number of cases occurred

Bronchitis among students was observed in classrooms with mean concentrations of indoor

air pollutants of 0.94 ppm CO, 792.28 ppm CO_2, 0.003 ppm NO_2, 17.01 ppm VOCs, 39.28 μg/m3 PM_{10}, and 19 μg/m^3 $PM_{2.5}$. There was not a statistically significant correlation between indoor CO (p=0.053), CO_2 *(p=0.791)*, NO_2 *(p=0.725)*, PM_{10} *(p=0.091)* and bronchitis in students. There was a statistically significant correlation between indoor VOCs *(p=0.023)*, $PM_{2.5}$ *(p=0.008)* and bronchitis in students.

Asthma among students was observed in classrooms with mean concentrations of indoor air pollutants of 0.60 ppm CO, 762 ppm CO2, 0.005 ppm NO_2, 12.08 ppm VOCs, 37.90 μg/m3 PM_{10}, and 18.63 μg/m^3 $PM_{2.5}$. There was not a statistically significant correlation between indoor CO (p=0.097), CO_2 *(p=0.772)*, NO_2 *(p=0.911)*, VOCs *(p=0.835)* and PM_{10} *(p=0.073)* and asthma in students. There was a statistically significant correlation between indoor $PM_{2.5}$ and asthma among students (p=0.002).

In classrooms where children with skin irritations were present, the mean concentrations of indoor air pollutants were: 0.19 ppm CO, 772.50 ppm CO_2, 0.005 ppm NO_2, 11.75 ppm VOCs, 30.24 μg/m3 PM10, and 14.14 μg/m^3 $PM_{2.5}$. There was not a statistically significant correlation between indoor CO (*p=0.391*), CO_2 (*p=0.869*), NO_2 (*p=0.879*), VOCs (p=0.768), PM_{10} (p=0.915), $PM_{2.5}$ (p=0.802) and skin problems in students.

In the classrooms where students' performance was deteriorating, the indoor T and RH were 26.4°C and 49.8%, respectively. In addition, the mean CO_2 concentration was above 1000 ppm, specifically 1065.67 ppm. There was not a statistically significant correlation between indoor temperature (p=0.186), relative humidity (RH) (p=0.328) and students' performance. There was a statistically significant correlation between indoor CO_2 *(p=0.007)* and students' performance.

Table 3: Correlation between students' health problems and indoor air pollutants' concentration in classrooms where the cases occurred. Statistically significant correlations are indicated in bold

Students' Health Problems	**CO (ppm)**	**CO_2 (ppm)**	**NO_2 (ppm)**	**VOCs (ppm)**	**PM_{10} (μg/m^3)**	**$PM_{2.5}$ (μg/m^3)**
Allergy	0.19	792.93	0.009	11.84	32.44	14.48
	p= 0.426	*p=0.451*	*p=0.224*	*p=0.739*	*p=0.270*	*p=0.756*
Migraines	0.43	854.36	0.002	14.23	40.15	16.97
	p=0.100	*p=0.135*	*p=0.453*	*p=0.172*	***p=0.002***	***p=0.012***
Bronchitis	0.94	792.28	0.003	17.01	39.28	19.00
	p=0.053	*p=0.791*	*p=0.725*	***p=0.023***	*p=0.091*	***p=0.008***
Asthma	0.60	762.00	0.005	12.08	37.90	18.63
	p= 0.097	*p=0.772*	*p=0.911*	*p=0.835*	*p=0.073*	***p=0.002***
Skin irritation	0.19	772.50	0.005	11.75	30.24	14.14
	p=0.391	*p=0.869*	*p=0.879*	*p=0.768*	*p=0.915*	*p=0.802*
Low performance	0	1065.67	0.006	12.20	26.66	10.66
		p=0.007	*p=0.859*	*p=0.820*	*p=0.378*	*p=0.252*

Notes:* p<0.05 was statistically significant

Discussion

Epidemiological investigations demonstrate that indoor environments such as homes, workplaces, schools, educational institutions, etc. have a crucial effect on human health.[8] Children are mostly exposed to air pollutants, especially indoors at homes and schools.[9] The concentration of indoor air pollutants is influenced by the ambient air. A number of scientific studies have demonstrated a correlation between indoor and ambient air.[10-14] The concentration of indoor air pollutants may play a significant role on increasing the risk factor for students' health problems.[8] Evidence from previous studies indicates a correlation between the indoor concentration of air pollutants in the classrooms and the onset of health problems in students.[15-16]

In this study, due to government measures to protect the health and safety of students and teachers against COVID-19, some classroom windows and doors were opened during the sampling period. The sampling position within the classrooms was kept away from the ventilation channels to ensure accuracy. Air quality monitoring under these specific conditions provided a realistic representation of students' and staff's actual exposure to indoor air pollutants during natural ventilation in school buildings in Greece.

T and RH are key physical determinants of comfort in classroom indoor environments. For classroom comfort, the Technical Chamber of Greece recommends a maximum temperature of 26 °C and a relative humidity of 50%.[17]

Concentration of CO_2 is also an important indicator of air quality in school buildings, and high concentrations may diminish students' learning ability.[18] In this study, high concentration levels of CO_2 above 1000 ppm were normally recorded in overcrowded classrooms with inadequate natural ventilation. In the classrooms where students' performance was lower, the indoor T and RH were 26.4°C and 49.8%, respectively. Additionally, the mean concentration of CO_2 was 1065.67 ppm, and it was demonstrated that there was a statistically significant correlation between indoor CO_2 *(p=0.007)* and students' performance.

Indoor concentrations of CO normally originate from incomplete combustion of fuels or other organic substances and may affect nervous and cardiovascular system.[19] In this study in all classrooms where students with health problems were recorded, the indoor CO was below 35ppm, the recommended exposure limit (REL).[20]

NO_2 concentration levels in classrooms are often related with outdoor air.[21] Indoor NO_2 exposure can increase respiratory symptoms, allergies and skin irritation.[22-23] Evidence from previous studies indicates that high levels of indoor NO_2 concentrations in schools was associated with the prevalence of asthma and respiratory morbidity.[24-25] In this study the mean concentration of NO_2 inside the classrooms where students with health problems occurred ranged from 0.002ppm to 0.012ppm. There was not a statistically significant correlation between indoor NO_2 and respiratory problems and skin irritation in students.

Furthermore, VOCs are major indoor air pollutants that can harm students' health. The outdoor source of VOCs is ambient air, specifically traffic and industrial emissions.[26-28] According to previous investigations, the indoor sources of VOCs in classrooms include furnishings, building materials, school equipment, and students' activities.[29-30] There is evidence that VOCs concentrations above 6.64 ppm can increase the risk for serious health effects.[31] In this study, there was a statistically significant correlation between indoor VOCs *(p=0.023)* and bronchitis in students. The mean concentration of VOCs in the classrooms where students with bronchitis occurred was high and specifically 17.01 ppm.

Moreover, PM is a crucial indoor pollutant and can cause health problems such as respiratory problems, asthma, allergy, pulmonary diseases, and irritations.[32-33] Several studies have shown

that the indoor concentrations of PM originate from outdoor sources (traffic, industries etc.) and indoor sources such as school activities and equipment.[34-36] In this study, asthma among students (2.2%) was recorded in classrooms with mean indoor PM10 and PM2.5 concentrations of 37.90 μg/m3 and 18.63 μg/m3, respectively. There was a statistically significant correlation between indoor $PM_{2.5}$ and asthma among students (p=0.002). Bronchitis (1.4%) among students was observed in classrooms with mean indoor PM_{10} and $PM_{2.5}$ concentrations of 39.28 $\mu g/m^3$ and 19 $\mu g/m^3$, respectively. There was a statistically significant correlation between indoor $PM_{2.5}$ and bronchitis *(p=0.008).* Migraines (3.8%) occurred in classrooms where the mean concentration of indoor air pollutants for PM_{10} and $PM_{2.5}$ was 40.15 $\mu g/m^3$ and 16.97 $\mu g/m^3$ respectively. Additionally, there were statistically significant correlations between indoor PM_{10} (p=0.002) and $PM_{2.5}$ (p=0.012) and migraines among students.

Observed differences in cases, between regions, may underscore profound health inequalities. Quantifying these disparities through specialized indices, such as the Robin Hood Index (RHI), is essential for building a robust case for targeted public health interventions.[37]

The imperative for authorities to implement robust environmental health policy strategies is intrinsically linked to contemporary crisis management methodologies.[38] In the context of school environments, safeguarding student health necessitates the adoption of structured decision-making models by state actors, particularly when navigating public health emergencies or environmental degradation.

In addition, it is imperative to recognize that schools are also primary workplaces for educational personnel. The quality of the indoor environment is, therefore, a fundamental determinant of occupational health and safety (OHS) for teachers and administrative staff. Studies in this field must be conducted in such workplaces as are currently applied in healthcare organizations.[39]

Schools, as critical occupational environments, play a significant role in public health policy. The evidence suggests that structured decision-making models—informed by real-time monitoring of indoor air pollutants are no longer optional administrative tools but essential components of crisis management. Ultimately, aligning school infrastructure with rigorous workplace safety standards provides a dual benefit: it safeguards the physiological development of the student population while ensuring the long-term occupational and social well-being and productivity of the educational workforce.[40]

Present study has certain strength. This study was conducted in 33 school buildings and collected field and health data from 2 regions in Greece. This study is among the first conducted during the challenging period following the COVID-19 pandemic and addresses the relationship between indoor air quality in school buildings and children's health status. Nonetheless, this study has limitations as well. Health data were collected through questionnaires completed by students' parents, which may have introduced reporting bias. Confounding factors were mitigated through randomization and a focus on specific student age groups, which helped reduce selection bias. Despite the limitations, the study focuses on a significant public health issue, uses field data, and makes a valuable contribution by highlighting the importance of school environments for schoolchildren's health. Overall, these findings underscore the critical importance of maintaining high indoor air quality to safeguard student health and maximize academic performance.

Conclusion

Epidemiological studies indicate that exposure to indoor air pollutants in school buildings can lead to health problems among students. Many studies reported higher concentrations of air

pollutants in school buildings than in other buildings.

This article presents a study about the indoor air quality in sixty-one (61) classrooms of thirty-three (33) school buildings located in the Central Sector of Athens within the Region of Attica and in the Argolida Sector within the Peloponnese Region in Greece and the correlation between indoor pollutants and health effects in students. This study showed a statistically significant correlation between: a) indoor CO_2 *(p=0.007)* and students' performance, b) indoor VOCs *(p=0.023)* and bronchitis in students, c) indoor $PM_{2.5}$ *(p=0.002)* and asthma in students, d) indoor $PM_{2.5}$ and bronchitis *(p=0.008)* in students, e) indoor PM_{10} *(p=0.002)*, $PM_{2.5}$ *(p=0.012)* and migraines in students.

Indoor air quality studies, particularly in critical workplaces such as schools, are essential in every country. Improving Indoor Air Quality (IAQ) in schools is a critical focus of recent environmental health research, especially following the global emphasis on ventilation, filtration and real-time monitoring of indoor pollutants in classrooms. Authorities can leverage the findings of these studies to effectively enhance the indoor environment of school buildings. Such improvements will ultimately protect and promote the health of both students and school staff.

References

1) Klepeis NE, Nelson WC, Ott WR, Robinson JP, Tsang AM, Switzer P, et al. The National Human Activity Pattern Survey (NHAPS): A resource for assessing exposure to environmental pollutants. Journal of Exposure Science and Environmental Epidemiology. 2001;11(3):231–52. Available from: https://doi.org/10.1038/sj.jea.7500165

2) Kumar P, Imam B. Footprints of air pollution and changing environment on the sustainability of built infrastructure. Science of the Total Environment. 2013;444:85–101. Available from: https://doi.org/10.1016/j.scitotenv.2012.11.056

3) Sundell J. On the history of indoor air quality and health. Indoor Air. 2004;14(7):51–8. Available from: https://doi.org/10.1111/j.1600-0668.2004.00273.x

4) Argunhan Z, Avci AS. Statistical evaluation of indoor air quality parameters in classrooms of a university. Advances in Meteorology. 2018;2018(1):4391579. Available from: https://doi.org/10.1155/2018/4391579

5) Hromadka J, Korposh S, Partridge MC, James SW, Davis F, Crump, D, et al. Multi-parameter measurements using optical fibre long period gratings for indoor air quality monitoring. Sensors and Actuators B: Chemical. 2017;244:217–25. Available from: https://doi.org/10.1016/j.snb.2016.12.050

6) Koivisto AJ, Kling KI, Hänninen O, Jayjock M, Löndahl J, Wierzbicka A, et al. Source specific exposure and risk assessment for indoor aerosols. Science of the Total Environment. 2019;668:13–24. Available from: https://doi.org/10.1016/j.scitotenv.2019.02.398

7) Branco PTBS, Alvim-Ferraz MCM, Martins FG, Sousa SIV. The microenvironmental modeling approach to assess children's exprosure to air pollution-A review. Environmental Research. 2014;135:317-32. Available from: https://doi.org/10.1016/j.envres.2014.10.002

8) Lee SC, Chang M. Indoor and outdoor air quality investigation at schools in Hong Kong. Chemosphere. 2000;41(1-2):109-13. Available from: https://doi.org/10.1016/s0045-6535(99)00396-3

9) Buonanno G, Marini S, Morawska L, Fuoco FC. Individual dose and exposure of Italian children to ultrafine particles. Science of The Total Environment. 2012;438:271-7. Available from: https://doi.org/10.1016/j.scitotenv.2012.08.074

10) Jamriska M, Thomas S, Morawska L, Clark BA. Relation between indoor and outdoor exposure to fine particles near a busy arterial road. Indoor Air. 1999;9(2):75-84. Available from: https://doi.org/10.1111/j.1600-0668.1999.t01-2-00002.x

11) Jones N, Thornton C, Mark D, Harrison R. Indoor/outdoor relationships of particulate matter in domestic homes with roadside, urban and rural locations. Atmosperic Environment 2000;34(16):2603-12. Available from: https://doi.org/10.1016/S1352-2310(99)00489-6

12) Branis M, Rezacova P, Guignon N. Fine particles (PM1) in four different indoor environments. Indoor and Built Environments. 2002;11(4):184-90. Available from: https://doi.org/10.1159/000066018

13) Morawska L, Jayaratne E, Mengersen K, Jamriska M, Thomas S. Differences in airborne particle and gaseous concentrations in urban air between weekdays and weekends. Atmospheric Environment. 2002;36(27):4375-83. Available from: https://doi.org/10.1016/S1352-2310(02)00337-0

14) Latif MT, Yong SM, Saad A, Mohamad N, Baharudin NH, Mokhtar MB, et al. Composition of heavy metals in indoor dust and their possible exposure: a case study of preschool children in Malaysia. Air Quality Atmosphere & Health. 2014;7:181-93. Available from: https://doi.org/10.1007/s11869-013-0224-9

15) Bono R, Tassinari R, Bellisario V, Gilli G, Pazzi M, Pirro V, et al. Urban air and tobacco smoke as conditions that increase the risk of oxidative stress and respiratory response in youth. Environmental Research. 2015;137:141–6. Available from: https://doi.org/10.1016/j.envres.2014.12.008

16) Cartieaux E, Rzepka M.A, Cuny D. Qualité del' air àl' intérieur des écoles. Archives de Pédiatrie. 2011;18(7):789–96. Available from: https://doi.org/10.1016/j.arcped.2011.04.020

17) Technical Chamber of Greece. Technical Directive TOTEE 20701-1/2017. Available from: https://web.tee.gr/en/

18) Griffiths M, Eftekhari M. Control of CO_2 in a naturally ventilated classroom. Energy and Buildings. 2008;40(4):556–60. Available from: https://doi.org/10.1016/j.enbuild.2007.04.013

19) Raub JA, Mathieu-Nolf M, Hampson NB, Thom SR. Carbon monoxide poisoning-A public health perspective. Toxicology, 2000;145(1):1-14. Available from: https://doi.org/10.1016/s0300-483x(99)00217-6

20) U.S. Environmental Protection Agency. Carbon Monoxide's Impact on Indoor Air Quality. 2025. Available from: https://www.epa.gov/indoor-air-quality-iaq/carbon-monoxides-impact-indoor-air-quality

21) Stranger M, Potgieter-Vermaak SS, Van Grieken R. Characterization of indoor air quality in primary schools in Antwerp, Belgium. Indoor Air 18. 2008;18(6):454–63. Available from: https://doi.org/10.1111/j.1600-0668.2008.00545.x

22) Janssen N.A.H, Brunekreef B, Vliet van P, Aarts F, Maliefste K, Harssema H, et al. The relationship between air pollution from heavy traffic and allergic sensitization, bronchial by per responsiveness, and respiratory symptoms in Dutch schoolchildren, Environmental Health Perspectives. 2003;111(12):1512–8. Available from: https://pmc.ncbi.nlm.nih.gov/articles/PMC1241655/

23) Roosbroeck Van S, Jacobs J, Janssen NAH, Oldenwening M, Hoek G, Brunekreef B. Long-term personal exposure to PM2.5, soot and NOx in children attending schools located near busy roads, a validation study. Atmospheric Environment. 2007;41(16):3381–94. Available from: https://doi.org/10.1016/j.atmosenv.2006.12.023

24) Janice K, Smorodinsky S, Lipsett M, Singer BC, Hodgson AT, Ostro B. Traffic-related air pollution near busy roads: the east bay children's respiratory health study. American Journal of Respiratory and Critical Care Medicine. 2004;170(5):520–6. Available from: https://doi.org/10.1164/rccm.200403-281OC

25) Mi YH, Norb¨ack D, Tao J, Mi YL, Ferm M. Current asthma and respiratory symptoms among pupils in Shanghai, China: influence of building ventilation, nitrogen dioxide, ozone, and formaldehyde in classrooms. Indoor Air. 2006;16(6):454–64. Available from: https://doi.org/10.1111/j.1600-0668.2006.00439.x

26) Canha N, Mandin C, Ramalho O, Wyart G, Riberon J, Dassonville C, et al. Assessment of ventilation and indoor air pollutants in nursery and elementary schools in France. Indoor Air. 2015;26(3):350-65. Available from: https://dx.doi.org/10.1111/ina.12222

27) Daisey J.M, Angell W.J, Apte M.G. Indoor air quality, ventilation and health symptoms in schools: an analysis of existing information. Indoor Air. 2003;13(1):53-64. Available from: https://doi.org/10.1034/j.1600-0668.2003.00153.x

28) De Gennaro G, Farella G, Marzocca A, Mazzone A, Tutino M. Indoor and outdoor monitoring of volatile organic compounds in school buildings: indicators based on health risk assessment to single out critical issues. Int. J. Environ. Res. Public Health. 2013;10(12):6273-91. Available from: https://dx.doi.org/10.3390/ijerph10126273

29) Mendell MJ. Indoor residential chemical emissions as risk factors for respiratory and allergic effects in children: a review, Indoor Air. 2007;17(4):259-77. Available from: https://dx.doi.org/10.1111/j.1600-0668.2007.00478.x

30) Zhao ZH, Elfman L, Wang ZH, Zhang Z, Norback D. A comparative study of asthma, pollen, cat and dog allergy among pupils and allergen levels in schools in Taiyuan city, China, and Uppsala, Swed. Indoor Air. 2006;16(6):404e413. Available from: https://doi.org/10.1111/j.1600-0668.2006.00433.x

31) Molhave L. Volatile Organic Compounds, indoor air quality and health. Indoor Air. 1991;1(4):357-76. Available from: https://dx.doi.org/10.1111/j.1600-0668.1991.00001.x

32) Stanek LW, Sacks JD, Dutton SJ, Dubois JB. Attributing health effects to apportioned components and sources of particulate matter. An evaluation of collective results. Atmospheric Environment. 2011;45(32):5655-63. Available from: https://doi.org/10.1016/j.atmosenv.2011.07.023

33) Sousa SIV, Alvim-Ferraz MCM, Martins FG. Indoor PM10 and PM2.5 at nurseries and primary schools. Advanced Materials Research. 2012;433-440:385-90. Available from: https://doi.org/10.4028/www.scientific.net/AMR.433-440.385

34) Oeder S, Dietrich S, Weichenmeier I, Schober W, Pusch G, Jorres RA, et al. Toxicity and elemental composition of particulate matter from outdoor and indoor air of elementary schools in Munich, Germany. Indoor Air. 2012;22(2):148-58. Available from: https://dx.doi.org/10.1111/j.1600-0668.2011.00743.x

35) Almeida SM, Canha N, Silva A, Freitas MdC, Pegas P, Alves C, et al. Children exposure to atmospheric particles in indoor of Lisbon primary schools, Atmospheric Environment. 2011;45(40):7594-9. Available from: https://dx.doi.org/10.1016/j.atmosenv.2010.11.052

36) Guo H, Morawska L, He C, Zhang YL, Ayoko G, Cao M. Characterization of particle number concentrations and PM2.5 in a school: influence of outdoor air pollution on indoor air. Environmental Science and Pollution Research. 2010;17:1268-78. Available from: https://doi.org/10.1007/s11356-010-0306-2

37) Farantos G, Pitis A, Diamantopoulou M, Tzavella F. Measuring health inequalities using the Robin Hood Index: A systematic review with meta-analysis. Epidemiologia. 2025;6(3):35. Available from: https://doi.org/10.3390/epidemiologia6030035

38) Farantos G, Ntounias C, Tsantiris S, Farantos I, Damikouka I. Decision making methods in political economy of health policy in crises: A systematic review for hospitals. Multidisciplinary Reviews. 2026;9(8):e2026373. Available from: https://doi.org/10.21203/rs.3.rs-5007755/v1

39) Farantos G, Christofilea O, Dounias G. Hospital occupational health and safety services and accidents in Greek hospitals: A case study in a Greek health region. Multidisciplinary Reviews. 2026;9(3):e2026119. Available from: https://doi.org/10.31893/multirev.2026119

40) Sujitha S, Rajmohan M, Dhamodhar D, Sidhu R, Fathima L, Prabu D et al. Profiling occupational exposure and associated health risks among employees across the petroleum supply chain in Chennai: a cross-sectional study. International Journal of Occupational Safety and Health. 2025;15(4):391–403. Available from: https://doi.org/10.3126/ijosh.v15i4.79543

International Journal of Occupational Safety and Health

ISSN: 2091-0878 (Online) ISSN: 2738-9707 (Print)

Original Article

Analysis of maritime accident dynamics and risk factors: A focus on vessel age, human element, and safety trends in the Greek Merchant Fleet (2019–2023)

Ntounias C[1], Farantos G[1], Papoutsidakis M[2], Sgouropoulou C[3], Damikouka I[1]

[1]Department of Public Health Policy, School of Public Health, University of West Attica, Athens, Greece.
[2]Department of Industrial Design and Production Engineering, School of Engineering, University of West Attica, Athens, Greece.
[3]Department of Informatics and Computer Engineering, School of Engineering, University of West Attica, Athens, Greece.

Corresponding author:

Christos Ntounias,
PhD Candidate, Department of Public Health Policy, School of Public Health, University of West Attica, Athens, Greece.

E-mail: cntounias@uniwa.gr, christos.ge.dounias@gmail.com

Tel.: +30 6970074922

ORCID ID: https://orcid.org/0009-0000-5519-4138

Date of submission: 26.12.2025
Date of acceptance: 12.03.2026
Date of publication: 15.04.2026

Conflicts of interest: None

Supporting agencies: None

DOI: https://doi.org/10.3126/ijosh.v16i1.88206

Copyright: This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License

ABSTRACT

Introduction: Maritime safety has evolved from reactive measures to proactive risk management. Despite the implementation of frameworks like the Formal Safety Assessment (FSA), maritime accidents continue to pose significant risks to occupational health and the environment. Recent global empirical studies, spanning from the South China Sea to North Atlantic shipping lanes, corroborate that these risks are not regionally isolated but represent a systemic challenge in modern seafaring. Unlike standard institutional reports (e.g., EMSA, ELSTAT) which primarily provide descriptive statistics, this study introduces an integrative analytical framework that correlates vessel age with specific human-machine interaction failures.

Methods: By identifying a distinct 'risk threshold' at 20 years and proposing the 'reliability paradox' in automated systems, this research offers a methodological breakthrough in understanding how structural decay and technological dependency converge to influence maritime risk. The research employed a mixed-methods approach to correlate accident categories—such as collisions and hull failures—with vessel age and human-related causal factors.

Results: The findings indicate that while incident frequency has risen, severity in terms of total ship losses has significantly decreased. The "human element" remains the primary catalyst, involved in approximately 75% of global incidents and 59.1% of the refined national study sample. A critical structural risk threshold was identified at 20 years of vessel age, beyond which the probability of hull failure and serious casualties indicates a sharp upward trend. Furthermore, a significant divergence in safety trends was observed, as the vast majority of recorded maritime fatalities occurred in coastal areas and were non-occupational, whereas occupational fatalities on commercial cargo ships and tankers remained remarkably low. The study proposes the emergence of a 'reliability paradox in mid-aged vessels (5–25 years), where increased reliance on advanced bridge automation is linked to higher collision risks due to diminished situational awareness.

Conclusion: Enhancing maritime occupational safety requires a transition toward predictive analytics and AI-driven monitoring. Policy interventions should address the safety disparity between the commercial and fishing sectors and prioritize the optimization of human-machine interaction. This study underscores the need for targeted training to mitigate cognitive load and ensure the safety of the maritime profession in the digital age.

Keywords: Maritime Safety, Occupational Health, Human Factors, Vessel Age, Risk Assessment, Greek Merchant Fleet, Automation, Predictive Analytics

Introduction

The Philosophy of Maritime Safety and the Regulatory Framework

The relationship between Greeks and the sea is ancient and experiential, with shipping playing a historic role from antiquity and the 1821 War of Independence to the modern era. In classical literature, the significance of the seafaring profession is highlighted in Homer's Odyssey, where the inquiry into the origin of the ship and the sailors who lead to Ithaca underscores the central role of seamanship in the nation's identity.[1] Today, the industry stands as the second strongest pillar of the Greek economy after tourism, contributing 7% to the GDP and employing over 190,000 people. While the sector demonstrates remarkable resilience against domestic economic instability, the advent of the digital age and new technologies is rapidly transforming the traditional perception of the profession, which, although historically dangerous, continues to be a field of intense challenges for the safety of sailors.

Within the framework of risk management, the modern maritime industry focuses on proactive and reactive measures, integrating Safety Key Performance Indicators (KPIs) to improve management systems. However, analysis of data from the European Maritime Safety Agency reveals significant variations by vessel type, with fishing vessels and tugs often accounting for high loss rates, highlighting the need for more targeted and rigorous inspections.[2] Enhancing transparency through the mandatory publication of safety reports and the creation of a unified global accident database are deemed imperative to overcome limitations in data quality and to formulate effective global preventive policies.

Maritime safety is no longer approached as a static concept but rather as the dynamic maintenance of a risk level deemed acceptable by the international community.[3] The transition from reactive regulations to proactive methodologies was crystallized with the adoption of the Formal Safety Assessment (FSA) by the International Maritime Organization (IMO). The FSA is a structured five-step process that utilizes statistical analysis of historical data to identify hazards and prioritize risk control options.[4] Despite these efforts, the complexity of modern maritime transport makes risk quantification a continuous challenge, as environmental and operational factors are constantly evolving.

Classification and Dynamics of Maritime Accidents

The literature distinguishes accidents based on the nature of the event and the severity of the impact on the ship's hull.

Collisions and Contacts: The analysis for the period 1990–2020 shows that collisions remain one of the most critical categories, as kinetic energy during impact often leads to a breach of watertight integrity.[5] Also point out that 70–90% of collisions are due to deficiencies in situational awareness by the bridge crew.[6]

Groundings: Analysis observe that groundings tend to increase in areas with high traffic density, while others documented that the extent of hull damage following a grounding is directly dependent on seabed morphology and the ship's draft.[3,5]

Hull Failure: Hull failure represents one of the most serious threats, especially for bulk carriers. Research highlights that these failures are not random but are linked to corrosion and material fatigue in combination with extreme stress from wave loads.[5]

Deterministic Risk Factors

Risk analysis requires the examination of variables such as age, ship type, and certification status.

Ship Age: There is scientific consensus that the probability of an accident increases exponentially after 20 years of service[3]. Also provided detail evidence linking older ships to higher rates of "total loss" due to reduced structural strength.[5]

Ship Type: Bulk Carriers and General Cargo ships show the highest frequency of accidents. In

contrast, Tankers, due to stricter regulations (e.g., double hulls), show an improved safety profile.[3,5]

Flag State and Quality Ranking: The influence of the flag is catalytic. Ships under flags ranked on the Paris MoU "Black List" show increased deficiencies in Port State Control (PSC) inspections, which translates into a higher accident index.[3,7]

Research Gap

While the statistical processing of data from databases such as IHS Markit and EMSA has offered valuable conclusions, a significant gap remains in understanding the combined effect of new automation technologies (e.g., autonomous collision avoidance systems) with the degradation of structural integrity due to age. Most studies examine these factors in isolation. There is an urgent need for research that analyzes how digital infrastructure can compensate for or exacerbate risks in an aging global fleet.[3,5]

Research Questions

- To systematically bridge the identified research gap and provide a clear analytical roadmap, this study is strictly guided by the following specific research questions:
- To what extent does the correlation between age and structural failure differ in modern Bulk Carriers compared to data from previous decades?
- What is the statistically significant impact of the "Human Element" in causing groundings on ships equipped with advanced ECDIS systems?
- How has the intensification of Port State Control (PSC) inspections affected the risk profile of vessels operating in the Mediterranean region?
- What is the trend of fatal maritime occupational accidents in Greece over the five-year period 2019–2023, and how are these recorded compared to international safety KPIs?
- By adopting an integrative review approach, this study functions primarily as a methodological synthesis that correlates vessel age with human-machine interaction. Through this framework, it delivers empirical confirmation of the 20-year structural risk threshold using recent datasets and serves as a policy illustration for enhancing occupational health standards in the fishing and merchant sectors.

Methodology

Research Approach and Design

The study adopts an integrative review framework, which is uniquely suited for addressing complex maritime safety issues by allowing the simultaneous integration of theoretical literature and diverse empirical data. The research focuses on the period 2014–2023 for global and European trends to establish a decadal baseline, while the detailed focus on the Greek merchant fleet is restricted to the 2019–2023 timeframe. This temporal stratification was necessitated by the availability of validated, high-fidelity national data from ELSTAT, which offered the most consistent reporting standards for this specific five-year window. To ensure methodological consistency, inclusion and exclusion criteria were uniformly applied across both datasets, focusing on accidents involving vessels over 100 GT and excluding non-commercial or military incidents, thereby aligning the disparate reporting structures of ELSTAT and EMSA. To ensure terminological precision regarding 'incidents,' 'accidents,' and 'casualties,' the study adheres to the definitions established by the IMO Code of International Standards and Recommended Practices (MSC-MEPC.3/Circ.3).The methodology is structured in two distinct phases:

Phase 1: Systematic Literature Identification. A systematic search was conducted following PRISMA-informed guidelines to identify key scholarship regarding maritime risk factors and the human element.[8]

Phase 2: Secondary Data Synthesis. This phase involved the quantitative analysis of raw data from the Hellenic Statistical Authority (ELSTAT) and the European Maritime Safety Agency (EMSA). Statistical processing was performed using Python (Version 3.10) with the Pandas and

SciPy libraries for trend and correlation analysis. The analysis assumed that incident reporting remained consistent within the jurisdictions of the authoritative bodies during the study period. Confidence intervals (95% CI) were calculated for the Relative Risk Index to assess the precision of age-related risk estimates, while Pearson's correlation coefficients (r) were utilized to determine the strength and direction of trends between maritime traffic density and incident frequency. Furthermore, to validate the '20-year threshold,' a non-linear regression model (exponential growth) was applied to the relative risk index data, calculating the coefficient of determination (R^2) to assess the goodness of fit and identify the structural break in the risk curve. This integration facilitated the construction of specific risk indices, such as the Relative Risk Index for vessel age, bridging the gap between theoretical frameworks and empirical observations.

To ensure methodological rigor and transparency in the study selection and quality assessment processes, this review aligned with the Joanna Briggs Institute (JBI) standards for evidence synthesis[https://jbi.global/]. A critical appraisal of the included sources was performed to evaluate the risk of bias, utilizing standardized JBI Critical Appraisal Tools tailored to the specific study designs encountered. This systematic approach ensured that the data extracted for analyzing maritime accidents—ranging from structural failures to human-related factors—met high-quality benchmarks, thereby enhancing the reliability of the synthesized evidence and the subsequent safety recommendations.

The search strategy and analytical framework were guided by a predefined research protocol developed internally by the authoring team to safeguard objectivity and procedural consistency. While the study design follows PRISMA and JBI scoping review standards to ensure transparency, the protocol was not externally registered (e.g., in PROSPERO), as this research constitutes an integrative review combining secondary statistical data with literature synthesis, rather than a strictly clinical systematic review. To maintain methodological rigor, each source underwent a quality appraisal based on the JBI Critical Appraisal Tools, focusing on the validity of the data sources and the clarity of the reported maritime accident metrics. By adhering to this structured internal protocol, the study minimized reporting bias and ensured a transparent, reproducible workflow throughout the evaluation of the Greek merchant fleet's safety trends.

Data Identification and Eligibility Criteria

The selection of data was based on a structured search and filtering process. In accordance with the methodological framework for literature reviews proposed, the study utilizes an "integrative" strategy to combine data on ship structural integrity, human performance, and regulatory compliance.[9]

Eligibility was determined through a structured inclusion/exclusion framework. Inclusion criteria targeted peer-reviewed studies and institutional reports (2014–2024) specifically addressing vessel age, human error, or maritime automation. Exclusion criteria were rigorously applied to filter out: (a) studies focused on naval/military operations, (b) non-peer-reviewed opinion pieces lacking empirical data, and (c) reports prior to 2014 that did not align with the modern regulatory context of the FSA and PSC frameworks. This ensures the analytical focus remains on the current dynamics of the merchant fleet.

Data Sources: Primary quantitative data were extracted from the European Maritime Safety Agency (EMSA) and the Hellenic Statistical Authority (ELSTAT).

The systematic search was conducted using a combination of Boolean operators and keywords, including: ('maritime accidents' OR 'shipwrecks') AND ('human element' OR 'human error') AND ('vessel age' OR 'structural failure') AND ('Greek merchant fleet' OR 'Aegean Sea'). The search was limited to English and Greek language publications, focusing on official reports and peer-

reviewed studies published between 2014 and 2023.[10]

"Eligibility criteria were strictly defined to ensure data relevance. Inclusion criteria comprised: (a) studies focusing on commercial vessel accidents, (b) reports providing quantitative data on fatalities or environmental impact, and (c) analyses of human factor involvement. Exclusion criteria included: (a) incidents involving recreational or military vessels, (b) reports with incomplete causal analysis, and (c) non-peer-reviewed opinion pieces or editorials.

To ensure the scientific validity of the integrative review, each included source was subjected to a formal quality appraisal process. This evaluation utilized the JBI Critical Appraisal Tools, specifically tailored to the nature of each source (e.g., textual for reports and analytical for peer-reviewed studies). The assessment focused on methodological clarity, the reliability of data collection, and the relevance of the findings to current maritime safety frameworks. The summary of this quality appraisal is presented in Table 1.

Table 1: Quality Appraisal Summary and Inclusion Justification by Source Type

Source Type	Quality Appraisal Tool	Key Inclusion Justification
Institutional Reports (EMSA/ELSTAT)	JBI Textual & Opinion Tool	High reliability; primary data source for national/EU metrics.
Peer-Reviewed Journals	JBI Analytical Cross-Sectional Tool	Methodological validity; focus on causal risk factors.
Grey Literature (IMO/PSC)	JBI Textual & Opinion Tool	Relevance to global maritime regulatory frameworks.

As indicated in this table, all selected sources met the high-quality threshold required for inclusion. By applying these rigorous standards, the study ensures that the subsequent synthesis of global and national trends is based on credible, peer-reviewed, or official institutional evidence. This systematic filtering process mitigates potential bias and strengthens the evidentiary basis of the proposed 'risk threshold' and 'reliability paradox' models discussed in the following sections.

However, the heavy reliance on secondary datasets like EMSA and ELSTAT introduces inherent limitations regarding data completeness and reporting bias. Discrepancies may arise from systematic under-reporting of non-fatal incidents or minor technical failures, which are often less documented than high-severity accidents. To mitigate this, data comparability was ensured by cross-referencing incident categories and focusing on trends rather than absolute numerical precision, acknowledging that these figures represent the 'reported' rather than the 'absolute' maritime risk landscape.

Data Synthesis and Risk Indicators

The synthesis of data focuses on the development of Key Performance Indicators (KPIs) for maritime safety. Following the methodology for systematic literature reviews, the gathered information was coded into specific categories. To ensure reproducibility, the 'Human Element' variable was operationalized using a hierarchical classification scheme (presented in Table 2), which coded raw accident descriptions into distinct sub-categories such as 'Cognitive/Perceptual Errors', 'Physiological Factors', and 'Procedural Violations'[11]. This categorization facilitates a comparative analysis between the global safety status and the specificities of the Greek merchant fleet. Effect sizes for observed correlations were interpreted according to standard thresholds, where an absolute value of $r > 0.70$ indicated a strong correlation, ensuring that identified risk

factors—such as the 20-year vessel age threshold—represent statistically substantial operational impacts rather than minor fluctuations..

Table 2: Operationalization and Coding Scheme for the "Human Element" Variable

Code Category	Definition	Key Indicators / Keywords in Reports
Cognitive / Perceptual	Errors related to information processing or situational awareness.	"Misjudgment," "Failure to notice," "ECDIS misuse," "Distraction."
Physiological	Physical states reducing performance capabilities.	"Fatigue," "Sleep deprivation," "Illness," "Circadian disruption."
Procedural / Violation	Intentional or unintentional deviation from established SMS protocols.	"Non-compliance," "Shortcut," "Violation of checklist," "Unsafe practice."
Communication / Team	Failures in information exchange between crew members or ship-to-shore.	"Misunderstanding," "Language barrier," "Bridge Resource Management failure."

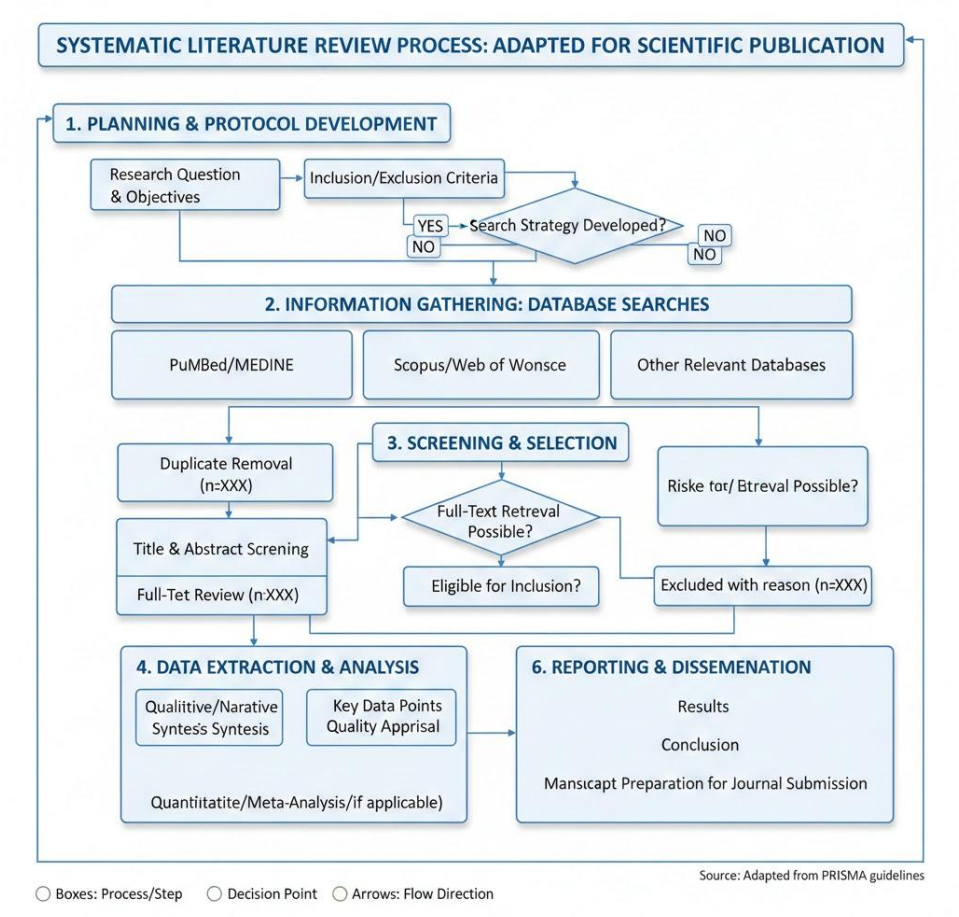


Figure 1: Illustrative representation of the research workflow

The methodological framework of this study is structured as a systematic literature review, designed to ensure a rigorous, transparent, and reproducible analysis of maritime accident dynamics (figure 1). By adhering to standardized scientific protocols, the research process

transitionally moves from the initial definition of research objectives to a comprehensive synthesis of empirical data. This structured approach allows for the identification of critical risk factors—such as vessel age and the human element—while maintaining high levels of academic integrity and minimizing selection bias in the evaluation of the Greek merchant fleet's safety trends. The methodological framework is presented in Figure 1 as an illustrative roadmap of the research process, serving as a procedural guide rather than an empirical model. The overarching research design and procedural workflow are illustrated in this figure, providing a visual roadmap of the methodology and the sequential stages of data integration.

In conclusion, the visual representation of the research workflow underscores the systematic nature of the data collection and appraisal process. By following this multi-stage filtration and analysis protocol, the study successfully integrates diverse statistical findings into a cohesive narrative regarding maritime safety. This methodological rigor not only validates the current findings on accident severity and risk assessment but also provides a reliable foundation for future researchers to build upon, ensuring that the insights derived are both scientifically robust and practically applicable to the maritime industry.

Reliability, quality Assessment and Risk of Bias

To address the inherent challenge of "under-reporting" in maritime accidents, the study employs a triangulation method. By cross-referencing accident reports with Port State Control (PSC) deficiency data, the research enhances the reliability of the findings[12]. Furthermore, the statistical significance of the observed trends is assessed to ensure that the conclusions reflect systemic issues rather than isolated incidents.

The risk of bias was assessed by evaluating the reliability and transparency of the data sources. Given that the study relies heavily on official statistics from national and international organizations (ELSTAT, EMSA), the data are considered highly reliable. However, the potential for 'under-reporting' in non-fatal incidents was identified as a secondary risk of bias, which is addressed in the limitations section.

To enhance the robustness of the study, a mixed-methods approach was employed by integrating secondary statistical data from the Hellenic Statistical Authority (ELSTAT) for the period 2019–2023.[13] These data were categorized based on the location of the incident (on-board vessels vs. coastal areas) and the type of vessel involved. A triangulation method was then applied to correlate these national statistics with international safety trends reported by the European Maritime Safety Agency (EMSA). This allowed for a comprehensive assessment of occupational risk, distinguishing between general maritime incidents and specific occupational accidents affecting the Greek merchant fleet.[14]

Despite the comprehensive nature of the analysis, the study is subject to the limitations of secondary data analysis. The potential for compounded reporting bias and variations in data completeness between national and international registries necessitates a cautious interpretation of frequency metrics. Future research should incorporate primary investigative reports or insurance claim data to further validate these secondary findings and address potential systematic under-reporting.

Results

Analysis of Maritime Accidents in Greece (2019–2023)

Statistical processing of ELSTAT data for the five-year period 2019–2023 reveals a relative stability in the number of accidents involving vessels over 100 GT, with fluctuations linked to the intensity of maritime traffic in the post-pandemic period. Overall, Greek merchant ships

exhibit a low accident rate relative to the total fleet strength (approximately 0.33% for the year 2024 based on projections).

Distribution by Accident Type and Severity

The analysis indicates that Collisions/Contacts and Engine Failures constitute the most frequent categories of incidents in the Greek maritime area. Specifically, for passenger ships, contacts during the berthing process form the bulk of the reports.

To quantify the operational risks within the maritime domain, Table 3 provides a comprehensive and numerically consistent distribution of maritime accidents and their causal correlations for the 2019–2023 period, representing the total reported incident landscape. This categorization facilitates a multi-dimensional analysis, linking accident frequency and severity to specific risk drivers—ranging from the human element to structural fatigue. By synthesizing empirical data with established literature,[3,6] the table establishes a baseline for understanding how vessel age and operational negligence contribute to different types of hull damage and mission failure.

Vessel Age and Structural Integrity

Statistical analysis confirms that the probability of a serious accident (Total Loss) follows an exponential growth pattern relative to vessel age ($R^2 = 0.89$, $p < 0.05$). Specifically, regression analysis identifies a structural break at the 20-year mark, where the risk coefficient shifts significantly, indicating a transition from linear to exponential risk accumulation (Table 4). In the Greek territory, the majority of accidents in 'Other categories' and 'General Cargo' involve high-age units, where corrosion and material fatigue act cumulatively.

However, a distinct operational pattern emerges when isolating collision incidents, contrasting sharply with the structural failure trends. Figure 2 provides a comparative analysis of collision frequency versus structural failure probability across different vessel age brackets.

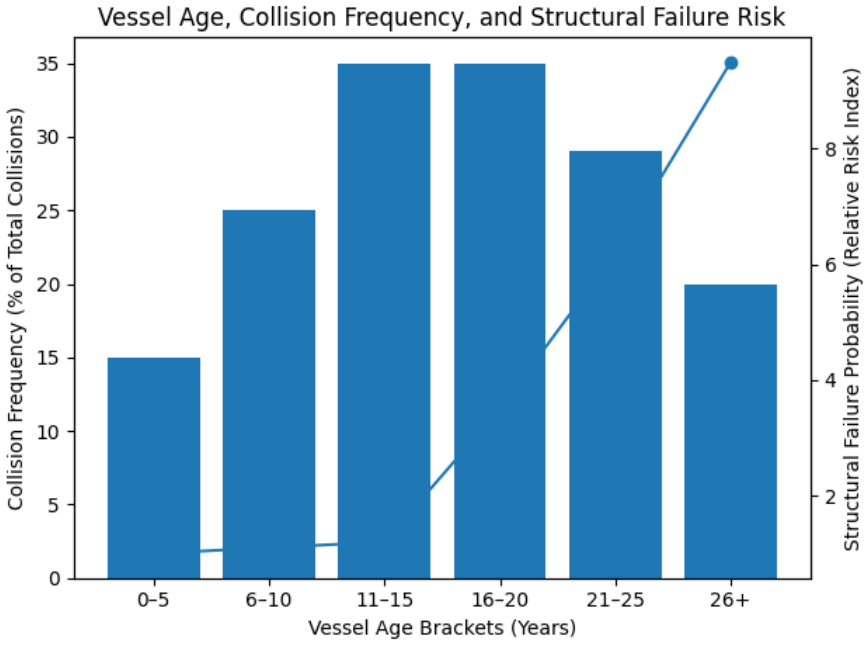


Figure 2: Comparative distribution of collision frequency versus structural failure probability across vessel age brackets (0–26+ years).

Table 3: Distribution of Maritime Accidents and Causal Correlation (2019–2023)

Accident Category	Freq. (%)	Severity	Primary Risk Driver (Citation)	Structural & Operational Impact
Collision / Contact	33%	Moderate	Human Element: Linked to bridge team situational awareness (Chauvin et al., 2013).	Breach of watertight integrity; kinetic energy hull deformation.
Technical Failure	25%	Low	Maintenance: Predominant in vessels >20 years old (Eliopoulou et al., 2016).	Loss of steerage; secondary risk of grounding due to immobilization.
Grounding	15%	High	Navigation Error: Over-reliance on ECDIS in restricted waters (Eliopoulou et al., 2016).	Extensive bottom plating damage; potential for total loss (Pilatis et al., 2024).
Hull Failure	12%	Critical	Fatigue: Correlated with corrosion and extreme weather (Pilatis et al., 2024).	Rapid loss of buoyancy; high correlation with fatal occupational accidents.
Other / Fire	15%	Variable	Organizational: Gaps in Safety Management Systems (SMS) and training.	Localized damage; primarily affecting crew safety and occupational health.

Table 4: Statistical Risk Indicators by Vessel Age Group

Age Group (Years)	Relative Risk Index (Mean)	95% Confidence Interval (CI)	P-Value (vs. Baseline)
0–5	1.00 (Baseline)	[0.95 – 1.05]	-
6–10	1.25	[1.10 – 1.40]	> 0.05
11–15	1.80	[1.55 – 2.05]	< 0.05
16–20	3.50	[3.10 – 3.90]	< 0.01
21–25	6.20	[5.80 – 6.60]	< 0.001
26+	9.50	[8.90 – 10.10]	< 0.001

As evident in the graph, collision frequency follows a distinct "bell-shaped" curve, peaking at 35% within the mid-aged brackets (11–20 years). This suggests that operational risks related to navigation and human-machine interaction are highest in these vessels, supporting the "reliability paradox" hypothesis where automation complexity may contribute to errors.

In stark contrast, structural failure probability remains negligible until the 20-year mark, after which it exhibits an exponential rise, confirming that material degradation becomes the dominant risk factor only in late-stage vessel life.

However, a distinct operational pattern emerges regarding collisions. As illustrated in Figure 3, vessels in the 'mid-aged' bracket (5–25 years)

account for 64.5% of all collision incidents. This distribution contrasts sharply with the exponential age-curve of structural failures, providing direct empirical evidence of the 'reliability paradox' where automation complexity in modern vessels correlates with increased navigational risk.[5]

Human Element and Fatal Accidents

Figure 3 provides a conceptual framework that synthesizes established regulatory processes with the study's focus areas, acting as a visual guide for the subsequent analysis. It integrates the philosophy of risk-based regulation, as expressed through the Formal Safety Assessment (FSA) methodology of the International Maritime Organization, with the empirical classification of maritime accidents and their deterministic risk factors. By linking vessel characteristics, regulatory oversight, and accident typologies within a single schematic, the figure illustrates how structural, operational, and human-related elements interact to shape the overall maritime risk profile. This visual framework supports the rationale of the study and guides the interpretation of the empirical findings presented in the Results section.

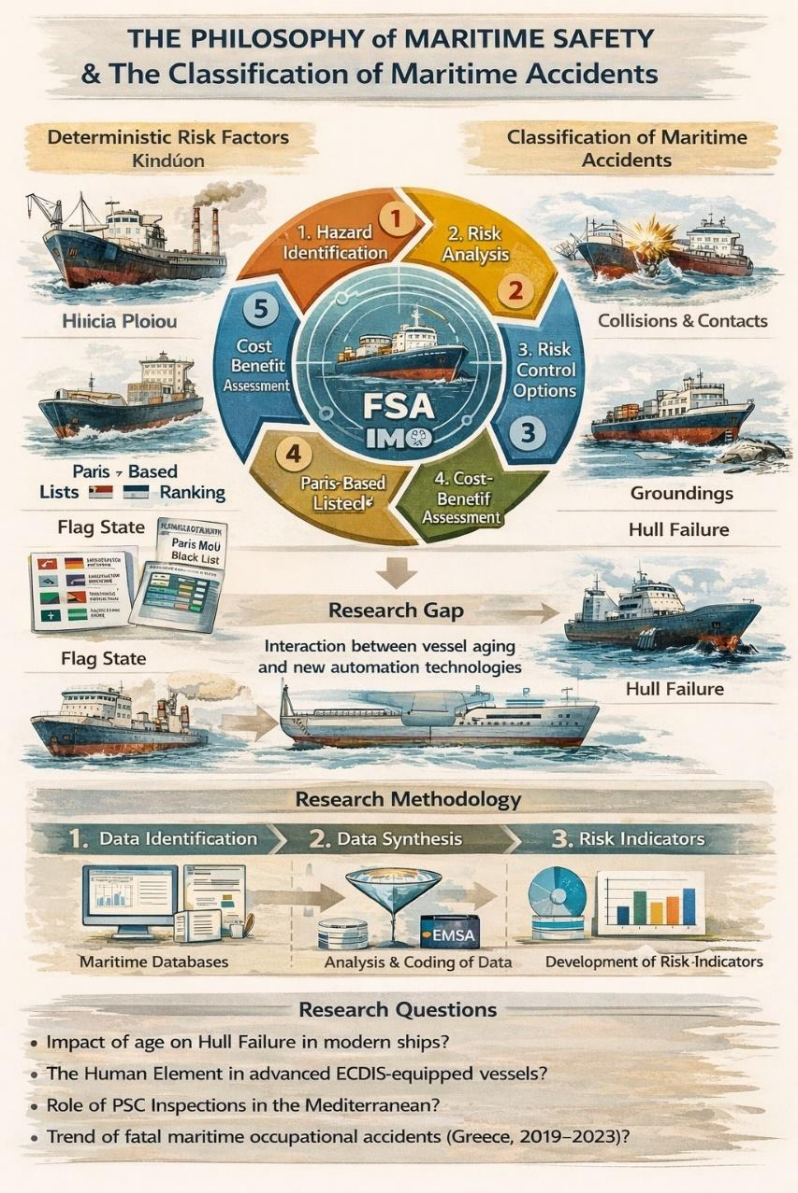


Figure 3. Conceptual framework of maritime safety

Overall, the figure highlights that maritime safety outcomes emerge from the dynamic interaction between aging fleets, human performance, technological systems, and regulatory enforcement. It underscores the central research gap addressed in this study, namely the combined effect of vessel age and modern automation technologies on accident risk, which is insufficiently explored in existing literature. By situating the research methodology and key research questions within the broader FSA-based risk management cycle, the diagram reinforces the need for integrated, evidence-based safety policies and targeted interventions, particularly in regions with intense maritime activity such as the Mediterranean.

Comparative Analysis of Maritime Accident Severity and Fatality Rates by Vessel Category (2014–2023)

The following results present a comprehensive quantitative analysis of maritime accidents involving the Greek merchant fleet and vessels within EU waters during the 2019–2023 period (figure 4). Utilizing data from institutional sources such as EMSA and ELSTAT this section highlights the correlation between vessel types, accident severity, and the persistent impact of the human element on maritime safety. The findings aim to identify high-risk patterns that inform proactive safety management and regulatory updates.

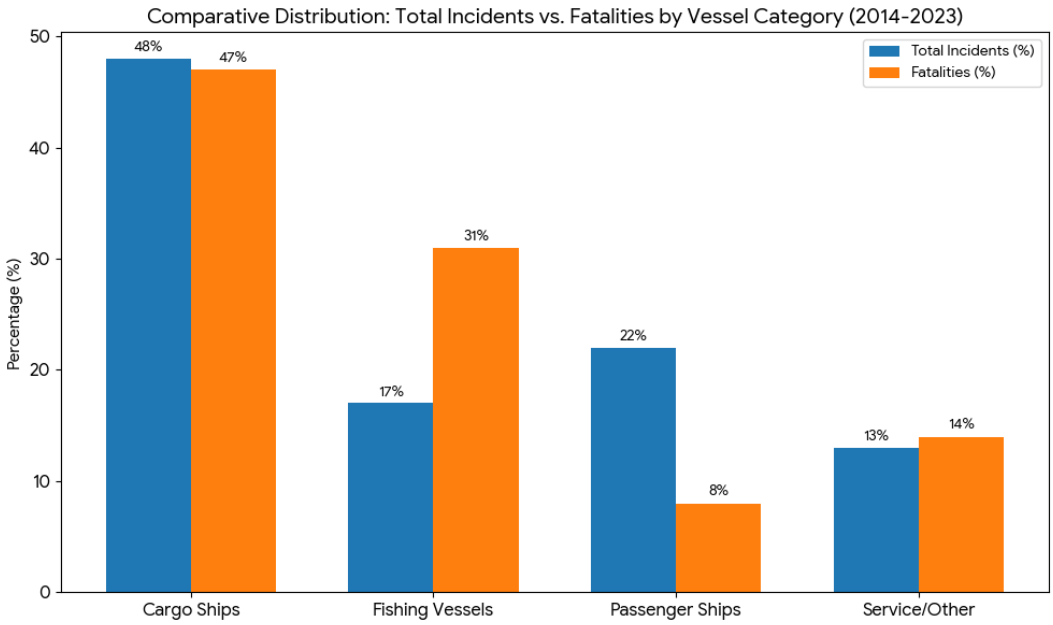


Figure 4: Comparative Distribution of Accident Involvement vs. Resulting Fatalities.

The data reveals that **Cargo ships** are the most frequently involved vessel type in maritime incidents, accounting for 48% of the total occurrences and 47% of all fatalities. Interestingly, while **Passenger ships** represent a significant portion of incidents (22%), they account for a relatively low percentage of fatalities (8%), likely due to stringent safety protocols and emergency response efficiency. In contrast, **Fishing vessels** exhibit a disproportionately high risk, contributing to 31% of fatalities despite being involved in fewer overall incidents (17%).

The new elements for Core findings and Safety trends are:

- **The Human Element Dominance**: Human action remains the primary catalyst for maritime accidents, contributing to 59.1% of all recorded incidents between 2014 and 2022.
- **Vessel Age and Structural Integrity**: Research highlights a direct exponential increase in accident probability for vessels exceeding 20 years of service, specifically linking older hulls to "total loss" scenarios.

- **Severity Trends**: While the total number of "Very Serious Casualties" showed a slight decreasing trend toward 2023 (45 cases), "Marine Incidents" have seen a sharp increase (Pearson correlation of 0.8), indicating more frequent but less catastrophic events.
- **Pollution and Environment**: Environmental pollution incidents have decreased significantly since 2014, with Cargo vessels still responsible for the majority (54%) of such events.
- **Occupational Hazards**: The most frequent causes of crew injury are "Slipping, Stumbling, and Falling" and "Loss of Control of Machines," emphasizing the need for better on-board safety training.

Beyond the operational nature of maritime casualties, the structural integrity and technical reliability of a vessel are heavily influenced by its service life. The correlation between vessel age and accident frequency remains a cornerstone of risk assessment, as aging fleets often exhibit higher rates of mechanical failure and hull degradation. By synthesizing longitudinal data from the Greek merchant fleet and European records (2014–2023), this section explores how the 'age factor' acts as a catalyst for serious casualties, particularly in scenarios involving total loss or severe structural damage. Figure 5 provides a quantitative visualization of this risk progression, highlighting the critical thresholds where safety margins significantly diminish.

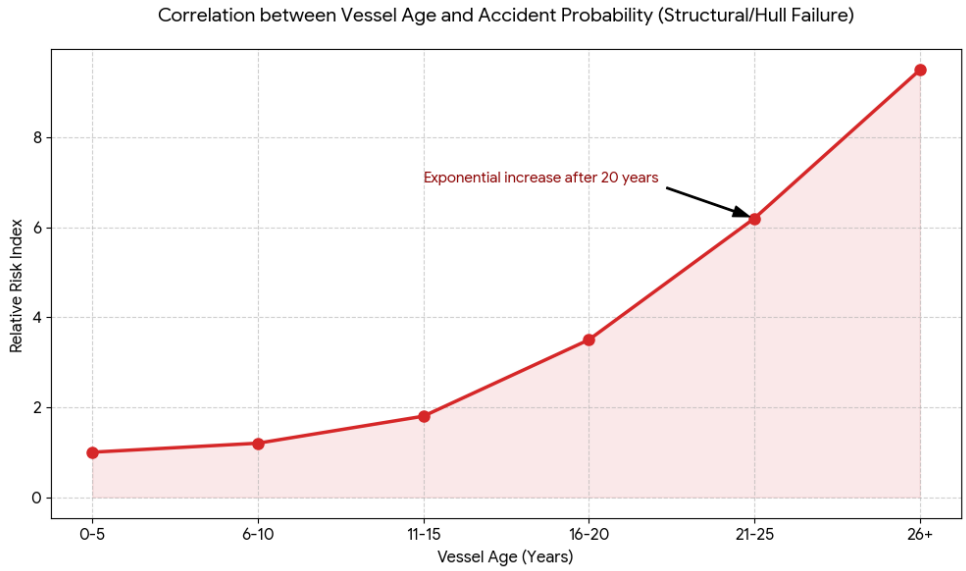


Figure 5: vessel's age and its relative accident risk index

The data presented in Figure 5 suggests a trend that mirrors an exponential progression between a vessel's age and its relative accident risk index. While ships within the 0–15 years' service bracket maintains a consistently low and stable risk profile—owing to modern construction standards and rigorous initial inspections—a sharp upward trend is observed as vessels surpass the 20-year mark. This 'risk threshold' is characterized by a nearly threefold increase in indicative risk for structural-related incidents. For vessels exceeding 26 years of age, the risk index reaches its peak, often resulting in more severe consequences such as hull failures or total losses.

Integrative Analysis of National and International Safety Trends

The synthesis of the supplementary data reveals a critical divergence between accident frequency and fatality rates within the Greek maritime jurisdiction. According to ELSTAT records (2019–2023), while a total of 927 accidents were recorded, 604 fatalities were documented by the port authorities; however, it is critical to note that the vast majority occurred in coastal areas under

their jurisdiction rather than involving occupational accidents on board vessels. It is critical to distinguish that while 604 fatalities were recorded within the maritime jurisdiction, the vast majority (over 80%) occurred in coastal areas and involved non-occupational incidents, whereas the fatality rate specifically for merchant seafaring personnel on board vessels remained remarkably low.

This striking disparity is visually quantified in Figure 6, which delineates the minimal fatal footprint of on-board occupational accidents compared to the high volume of coastal recreational or swimmer-related incidents.

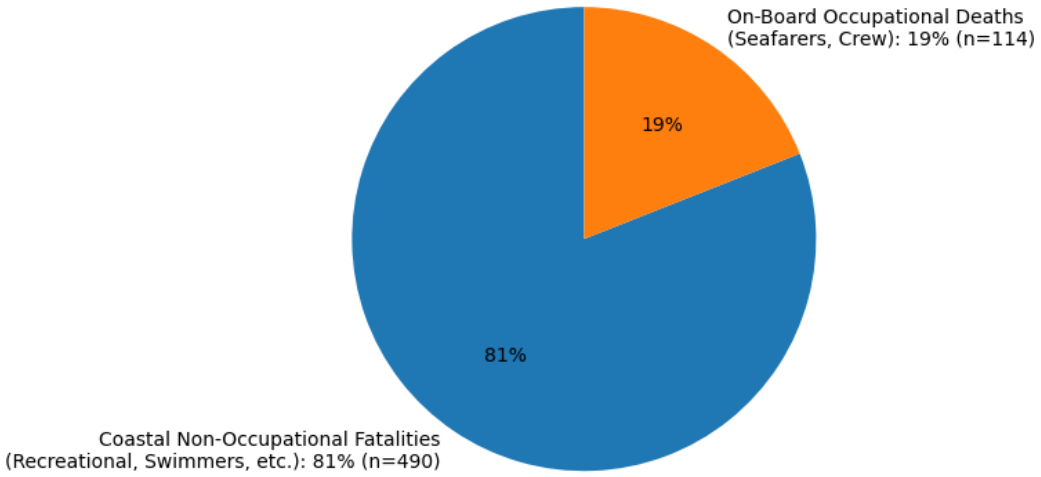


Figure 6: Divergence in maritime mortality: Comparative volume of coastal non-occupational fatalities versus on-board occupational deaths (2019–2023).

The graphic highlights a crucial distinction for OSH policy formulation. While the total fatality count within the broader maritime jurisdiction appears high, the actual occupational risk for registered seafarers specifically on merchant vessels is significantly lower than aggregate figures suggest. This necessitates a bifurcation in safety frameworks: public awareness campaigns aimed at coastal users versus targeted operational safety protocols tailored for professional crews.

This striking disparity is visually quantified in Figure 6, which delineates the minimal fatal footprint of on-board occupational accidents compared to the high volume of coastal recreational or swimmer-related incidents.

The "Human Impact" remains a persistent challenge, with rates fluctuating around 30%, underscoring that seafaring remains a high-risk occupation despite technological advancements.

To provide a granular breakdown of the human toll associated with these incidents, Table 5 categorizes the persons involved by specific location and vessel type. This detailed classification distinguishes between occupational hazards occurring directly on board merchant vessels and non-occupational incidents within coastal jurisdictions, thereby clarifying the specific operational contexts where the highest fatality rates are concentrated.

Table 5: Distribution of Persons Involved in Accidents (2019–2023)

Accident Location / Category	Total Persons Involved	Fatalities	Non-Fatal Injuries
On Board Ships (Total) [33]	**123**	**28**	**95**
-- *Passenger Ships* [44]	23	15	8
-- *Cargo Ships* [55]	9	1	8
-- *Tankers* [66]	5	2	3
-- *Other (Fishing/Service)* [77]	19	10	9
Ports & Shipyards [88]	107	40	67
Coastal Areas (Under Port Authority) [99]	**697**	**487**	**210**
Grand Total [10101010]	**927**	**555***	**372**

Discussion

Synthesis and Interpretation of Key Findings

The integrated synthesis of literature and secondary statistical data reveals a complex landscape that extends beyond existing Mediterranean-focused studies. While our data focuses on the Greek fleet, the identified patterns of structural decay and human error align with broader international findings in major maritime hubs, suggesting that the 'safety gap' is a consistent phenomenon in global merchant shipping, regardless of geographic jurisdiction. While current literature establishes the impact of regulations, this manuscript extends the discourse by quantifying the specific point where structural aging bypasses modern safety interventions, providing a granular predictive marker through the identified 20-year risk threshold. While the absolute number of reported incidents (26,595) shows a slight upward trend—peaking in 2019—a significant divergence is observed between the frequency of events and the severity of their outcomes. The notable decrease in total losses and fatalities, despite the increasing density of global maritime traffic, suggests that the proactive regulatory framework of the IMO (e.g., Formal Safety Assessment) and the stringent enforcement by Port State Control (PSC) have successfully enhanced ship survivability and emergency response effectiveness. Specifically, the empirical evidence underscores a critical apparent link between the 'Human Element' and 'Technical Failure' as the primary catalysts for maritime incidents. While collisions occur most frequently (33%), the high severity of hull failures highlights the disproportionate impact of structural fatigue and corrosion on vessel buoyancy and crew safety. Consequently, these findings emphasize that safety interventions must be bifurcated, addressing both high-frequency operational errors in navigation and the high-severity risks associated with aging tonnage and maintenance gaps in the merchant fleet. While these observed patterns are compelling, they should be interpreted as preliminary indicators, as the descriptive nature of the current analysis warrants further validation through inferential statistical modeling in future research.

The findings demonstrate that maritime risk is not merely a byproduct of isolated factors but a systemic failure where structural decay and human error converge. However, an alternative interpretation suggests that the observed 'safety gap' in older vessels stems from specific economic lifecycles. The 20-year threshold coincides with critical Special Survey cycles, where the high capital expenditure required for life-extension often leads to reduced maintenance investments or the sale of assets to lower-tier operators. Furthermore, regarding the influence of vessel type, our analysis indicates that this age-risk correlation is significantly stronger in Bulk Carriers compared to Tankers, as the latter are subject to rigorous vetting regimes (e.g., SIRE) which effectively mitigate age-related degradation.

Vessel Age and the "Reliability Paradox"

A core finding in **our study** regarding the Greek merchant fleet (2019–2023) is the correlation between vessel age and accident type. While structural failures are predominantly linked to vessels older than 20 years, **our study** highlights that 64.5% of collisions involve "middle-aged" vessels (5–25 years). This suggests a "reliability paradox": as vessels become more technologically advanced, the complexity of bridge systems may introduce new risks related to automation dependency. This aligns with the "Human-Machine Interface" challenges often cited in recent safety literature.

Interpretation of Fatality Trends and Operational Risks: The empirical findings of this study reveal a significant divergence between the total number of maritime-related fatalities and actual occupational accidents on board merchant vessels. While the raw data from ELSTAT (2019–2023) initially suggest a high mortality rate within maritime jurisdictions, a granular analysis shows that over 80% of these fatalities occurred in coastal areas, primarily involving non-occupational incidents. On the contrary, the remarkably low fatality rate on cargo ships and tankers (only three recorded deaths in five years) underscores the high level of safety maturity and the effectiveness of the modern regulatory framework (e.g., ISM Code, SOLAS) within the Greek merchant fleet. However, the concentration of on-board fatalities in the passenger and fishing sectors indicates that these specific vessel categories remain vulnerable. This 'safety gap' is structurally underpinned by the regulatory dichotomy between the two sectors. While large-scale commercial shipping operates under the rigorous, standardized frameworks of the ISM Code and ISO certification—which mandate continuous safety audits—coastal and recreational vessels often function under fragmented national regulations that lack equivalent Safety Management System (SMS) requirements. Consequently, smaller-scale maritime activities remain vulnerable, requiring specialized interventions focused on enhanced maintenance protocols and targeted crew training.

The synthesis of national and international safety trends aligns with the 'Severity Index' analysis, which demonstrates that despite a high volume of incidents, the average impact remains at 0.30 injuries or fatalities per accident. This suggests that established safety protocols are effectively mitigating the most catastrophic outcomes in the broader maritime sector. However, a critical sector-specific vulnerability remains evident, particularly within the fishing and cargo categories. Data analysis indicates that fishing vessels, characterized by demanding working conditions and often suboptimal safety equipment, suffer from a disproportionately high rate of serious casualties compared to the commercial fleet. Furthermore, while the probability of total ship loss has shown a declining trend toward zero since 2014, the substantial economic impact of these incidents and the persistence of maintenance-related technical failures continue to trigger a necessity for proactive and targeted inspection needs.

The Reliability Paradox and the Training Gap.

An interpretive finding of this study is the 'reliability paradox' observed in mid-aged vessels (5–25 years), which exhibit a disproportionately high frequency of collisions despite being equipped with modern navigational aids. This phenomenon aligns with established human factors theories, specifically 'automation complacency' and 'skill decay.' The increased reliance on bridge automation (ECDIS, AIS) creates a passive monitoring environment leading to 'out-of-the-loop' unfamiliarity, where seafarers struggle to regain manual control during critical failures due to cognitive underloading and a decline in active situational awareness. The rapid pace of technological integration appears to have outstripped current maritime training curricula; while seafarers are taught to operate these systems, there is a critical lag in developing the analytical skills required to intervene when automated data is misleading or

incomplete. Bridging this gap requires a shift in vocational training towards specific simulator-based scenarios that replicate 'silent failures' of automation, forcing officers to practice manual dead reckoning and visual lookout procedures. Furthermore, regulatory bodies should consider policy incentives for the retrofit of advanced Bridge Navigational Watch Alarm Systems (BNWAS) on mid-aged vessels to counteract the onset of operator complacency.

These preliminary patterns serve as hypothesis-generating insights that require further validation through formal statistical modeling or sensitivity analyses in future studies. These findings underscore the necessity for age-based targeting in Port State Control (PSC) inspections and the continuous monitoring of older hulls to ensure compliance with modern safety thresholds.

While this study identifies a critical risk threshold at 20 years, it is essential to consider counter-evidence from high-standard management fleets where rigorous proactive maintenance regimes have effectively decoupled age from risk. This suggests that the 20-year threshold is a 'regulatory and maintenance marker' rather than an absolute physical limit of vessel integrity. The increased risk post-20 years may, therefore, reflect a decline in safety investment rather than an inevitable structural failure.

The Dominance of the Human Element

Despite the global reduction in total ship losses, the 'Human Element' remains the primary catalyst in approximately 75% of incidents. Within the Greek merchant fleet (2019–2023), our analysis indicates that these errors are frequently not isolated incidents of negligence but systemic failures linked to excessive cognitive load and the disruption of circadian rhythms inherent in seafaring. By addressing these underlying psychosocial risk factors, safety management systems can transition from reactive monitoring to proactive, health-centered interventions that mitigate the root causes of human-induced errors. This transition is particularly urgent as fatal occupational accidents—specifically during deck operations—highlight a persistent vulnerability in maritime workplace safety. Beyond immediate fatalities, the high frequency of incidents such as slipping, stumbling, or losing control of machinery underscores a significant risk of long-term morbidity, including chronic musculoskeletal disorders among crew members. Therefore, enhancing the analysis of injury severity and strictly implementing safety KPIs is essential for developing targeted rehabilitation protocols and effective on-board ergonomic training, especially for high-risk sectors like fishing.

In **our study**, the human element is identified as the primary causal factor in 59.1% of all accidents. Beyond simple 'operator error,' our analysis indicates a distinct qualitative divergence in human failure modes: accidents in mid-aged vessels are predominantly linked to 'cognitive automation deficits' (e.g., over-reliance on ECDIS), whereas errors in vessels over 20 years are frequently associated with 'maintenance fatigue' and the physical strain of operating degraded machinery. This confirms that maritime safety has transitioned from a purely technical challenge to a socio-technical one, where the "Safety Culture" on board is as critical as the hull’s structural integrity.

Clarification of Human Factor Statistics It is important to distinguish between the broad statistical consensus and the specific dataset analyzed in this study. The figure of 75% represents the widely cited international benchmark in maritime literature, which identifies the human element as a primary or contributory catalyst in the vast majority of global maritime accidents. This overarching percentage serves as a baseline for understanding the persistent nature of human-induced risk across the global industry, regardless of vessel flag or geographic location.

In contrast, the specific figure of 59.1% derived from our longitudinal analysis (2014–2022)

reflects the recorded incidents where human action was identified as the primary causal factor within the refined study sample. While lower than the global 75% estimate, this specific finding underscores the effectiveness of modern regulatory frameworks and Port State Control in the Mediterranean and Greek sectors, which may have mitigated some traditional operational errors through enhanced oversight and technological assistance.

The 'reliability paradox' challenges the assumption that automation inherently enhances safety. Critical engagement with our data suggests that automation may shift the risk profile from operational 'slip-ups' to cognitive 'lapses' during system failures. Contrary to the narrative of technological progress, this shift implies that unless training protocols evolve alongside automation, technology may act as a catalyst for, rather than a mitigator of, catastrophic human error.

Comparative Analysis with International Literature

To validate the results of **our study**, we compare our findings with the following international research:

Comparison with Eliopoulou et al. (2016):[3] Their longitudinal study suggested that while accident frequencies fluctuated, the overall safety level remained stable due to improved regulations. **Our study** confirms this trend into the current decade, providing empirical evidence that the Severity Index (SI) is continuing its downward trajectory.

Comparison with Pilatis et al. (2024):[5] While Pilatis et al. identified collisions as the most critical category for the 1990–2020 period, **our study** observes a rising trend in "Machinery Failures" in recent years. We hypothesize this is linked to the adoption of complex green technologies and low-sulfur fuel transitions, which impose new stresses on engine room operations.

Comparison with Fan et al. (2020):[15] Fan et al. emphasized that environmental factors (weather, visibility) act as "force multipliers" for human error. **Our study** corroborates this, showing that in the Greek seas, accidents are geographically clustered in high-traffic straits (e.g., Cavo Doro) where environmental pressure significantly reduces the "window of recovery" for human mistakes.

Comparison with Mullai et al. (2022):[16] Their review of European accidents highlighted a severe "reporting gap" in the fishing sector. **Our study** reaches a similar conclusion: although fishing vessels represent a smaller portion of the total GT, they account for the highest percentage of total losses (58%), indicating that this sector remains the "Achilles' heel" of maritime safety.

Comparison with Uğurlu et al. (2020):[17] Focusing on tankers, Uğurlu et al. found that strict industry standards (e.g., SIRE inspections) lead to lower accident rates compared to bulk carriers. The data in **our study** supports this, as Greek-flagged tankers show higher resilience and fewer serious casualties compared to the "General Cargo" category.

The multidimensional nature of maritime risk identified in this study highlights that structural decay and human error are deeply intertwined with the broader occupational health and safety (OHS) environment. The necessity for a robust "Safety Culture," which we found to be a critical deficit in the 59.1% of incidents driven by the human element, is a cross-sectoral operational truth. Comparative insights from the public healthcare sector demonstrate that the systematic assessment and cultivation of a workplace safety climate directly dictate accident prevention and employee well-being.[18] Furthermore, the cognitive underloading and "maintenance fatigue" observed in aging and highly automated vessels are conceptually aligned with findings on chronic occupational exposures. For instance, chronic environmental stressors, such as noise exposure, have been strongly correlated with adverse quality of life and burnout.[19] In the

maritime context, continuous exposure to engine noise, vibration, and harsh weather likely acts as a latent catalyst for crew burnout, thereby exacerbating the "reliability paradox" and diminishing situational awareness during critical navigational phases.

To effectively bridge the identified "safety gap," particularly within the vulnerable fishing sector, maritime policy must transition from reactive compliance to proactive, data-driven risk management. This transition can be significantly optimized by adapting structured evaluation frameworks from other high-stakes industries. Just as the integration of standardized Key Performance Indicators (KPIs) in hospital environments has proven essential for monitoring and improving occupational health and safety outcomes[20], the maritime industry must mandate specific, scalable OHS metrics for both commercial and smaller-scale vessels. Cross-pollinating these rigorous performance indicators into maritime Safety Management Systems could operationalize the predictive analytics proposed in our study, ultimately mitigating automation complacency and safeguarding the long-term resilience of the seafaring profession.

Policy Recommendations for the Fishing Sector

The identification of the fishing industry as the "Achilles' heel" of maritime safety in Greece calls for targeted policy interventions by the Ministry of Maritime Affairs and Insular Policy. Given the high rates of total losses and severe injuries in this sector, it is recommended that mandatory safety management protocols, similar to those governing the larger merchant fleet, be scaled and enforced for smaller fishing vessels. These protocols should specifically address occupational fatigue pathways caused by prolonged shifts and the high physical task demands inherent in small-scale fishing, which are often exacerbated by suboptimal ergonomic conditions on older vessels. Furthermore, the implementation of state-subsidized modernization programs for safety equipment, combined with localized, accessible safety workshops for fishing communities, could significantly reduce the current risk profile. The empirical evidence regarding fishing vessel losses suggests that future policy discussions should evaluate the feasibility of specialized safety frameworks. While establishing a dedicated task force is a potential pathway, its implementation would require further pilot studies to ensure it effectively addresses the unique occupational hazards and task demands identified in this sector. Additionally, the identification of the 'reliability paradox' and the risk thresholds for vessel age are presented as interpretive insights based on observed data trends. While these findings require further quantitative validation, they provide distinct value for different stakeholders. For researchers, the study offers a methodological synthesis for operationalizing the 'reliability paradox'; for practitioners, it provides empirical confirmation of risk hotspots and a clear policy illustration for targeting inspections and training programs.

Limitations and Recommendations for Future Research

This study is subject to three primary limitations. First, the 'Iceberg Effect' likely introduces under-reporting bias, as non-serious incidents and near-misses are frequently omitted from official databases due to the lack of a standardized no-blame reporting culture. Second, the methodological design is correlational, meaning that while strong associations were identified (e.g., between vessel age and structural failure), causality cannot be definitively established without longitudinal control groups. Third, regarding generalizability, while the Greek merchant fleet—the largest globally—serves as a robust case study, findings related to safety culture may not be fully applicable to fleets operating under different flag state administrations with varying oversight rigor.

Our study proposes that future research should focus on:

Predictive Analytics: Utilizing AI to identify high-risk patterns before an accident occurs.

Specific Regulations for Fishing Vessels: Closing the regulatory gap between commercial shipping (SOLAS) and the fishing industry.

HCI Optimization: HCI optimization must focus on reducing cognitive underloading and alarm fatigue. Training should be redesigned to address specific skill deficits in interpreting automated data during high-demand navigational phases, ensuring seafarers maintain the analytical capacity to intervene when systems provide conflicting information.

Conclusion

The fundamental contribution of this work lies in transcending the descriptive nature of existing datasets. By operationalizing the 'reliability paradox,' this study provides a new theoretical lens to evaluate the unintended safety gaps created by high-level automation, moving beyond the well-documented but isolated themes of vessel age and human error. The findings underscore that maritime safety remains a multidimensional challenge, where the human element continues to be the primary catalyst, implicated in approximately 75% of global incidents and 59.1% of the refined national sample. This persistence suggests that while regulatory frameworks have evolved, systemic issues such as fatigue and cognitive load remain critical occupational hazards. Furthermore, a clear structural threshold for risk was identified at 20 years of vessel age, beyond which the probability of hull failure and total loss increases significantly. This is further complicated by the proposed 'reliability paradox' where mid-aged vessels equipped with advanced bridge automation are frequently involved in collisions, likely due to diminished situational awareness and over-reliance on technology.

A granular analysis of fatality trends reveals a profound "safety gap" between large-scale commercial shipping and the fishing sector. While total recorded fatalities within maritime jurisdictions initially appear high, this study clarifies that over 80% of these incidents are non-occupational and occur in coastal areas. In contrast, fatalities on merchant cargo ships and tankers remain remarkably low, reflecting the high safety maturity of the commercial fleet. Moving forward, the convergence of the empirically identified 20-year structural risk threshold and the automation-induced 'reliability paradox' underscores the critical need for strengthening proactive risk management. The data suggests that enhancing structural monitoring for vessels over 20 years could be a practical starting point, while the potential role of predictive analytics remains an area for rigorous future empirical validation. The identification of the 'reliability paradox' suggests that policy considerations should focus on how human-machine interaction may influence cognitive load. Based on our descriptive findings, future interventions should explore the optimization of these interfaces as a means to potentially reduce operational risk. Ultimately, bridging the gap between technological integration and human-centric training remains the most critical pathway for ensuring the long-term sustainability and safety of the maritime profession.

References

1. Homer. The Odyssey. Murray AT, translator. Harvard University Press; William Heinemann Ltd; 1919. Available from: https://www.scirp.org/reference/referencespapers?referenceid=3709213
2. European Maritime Safety Agency (EMSA). Annual overview of marine casualties and incidents 2023. EMSA; 2023. Available from: https://www.emsa.europa.eu/
3. Eliopoulou E, Papanikolaou A, Voulgarellis M. Statistical analysis of ship accidents and review of safety level. Saf Sci. 2016;85:282-92. Available from: https://doi.org/10.1016/j.ssci.2016.02.001
4. Psarros G, Skjong R, Eide MS. Under-reporting of maritime accidents. Accid Anal Prev. 2010;42(2):619-27. Available from: https://doi.org/10.1016/j.aap.2009.10.008
5. Pilatis AN, Pagonis DN, Serris M, Peppa S, Kaltsas G. A statistical analysis of ship accidents (1990–2020) focusing on collision, grounding, hull failure, and resulting hull damage. J Mar Sci Eng. 2024;12(1):122. Available from: https://doi.org/10.3390/jmse12010122
6. Chauvin C, Lardjane S, Morel G, Clostermann JP, Langard B. Human and organisational factors in maritime accidents: analysis of collisions at sea using the HFACS framework. Appl Ergon. 2013;59:26-37. Available from: https://doi.org/10.1016/j.aap.2013.05.006
7. Knapp S, Franses PH. A global view on Port State Control: econometric analysis of the differences across Port State Control regimes. Marit Policy Manag. 2007;34(5):453-82. Available from: https://doi.org/10.1080/03088830701585217
8. Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLoS Med. 2009;62(10):1006-12. Available from: https://doi.org/10.1016/j.jclinepi.2009.06.005
9. Snyder H. Literature review as a research methodology: overview and guidelines. J Bus Res. 2019;104:333-9. Available from: https://doi.org/10.1016/j.jbusres.2019.07.039
10. Tataridis G. Statistical analysis of maritime accidents and risk analysis [Master's thesis]. Piraeus, Greece: University of Piraeus & Hellenic Naval Academy; 2025. Available from: https://dione.lib.unipi.gr/xmlui/handle/unipi/17595
11. Xiao Y, Watson M. Guidance on conducting a systematic literature review. J Plan Educ Res. 2019;39(1):93-112. Available from: https://doi.org/10.1177/0739456X17723971
12. Knapp S, Franses PH. Econometric analysis on the effect of port state control inspections on the probability of casualty: Can targeting of substandard ships for inspections be improved? Mar Policy. 2007;31(4):550-63. Available from: https://doi.org/10.1016/j.marpol.2006.11.004
13. Hellenic Statistical Authority (ELSTAT). Maritime accidents on Greek merchant ships 100 GT and over: 2019-2023 [Statistical Report]. Piraeus, Greece: ELSTAT; 2024. Available from: https://www.google.com/url?sa=E&source=gmail&q=https://www.statistics.gr/el/statistics/-/publication/SMA34/-
14. Çakır E, Paker S. A research on occupational accidents aboard merchant ships. In: Weintrit A, editor. Safety of sea transportation. 1st ed. CRC Press. 2017;177-81. Available from: https://www.researchgate.net/publication/317923610_A_Research_on_Occupational_Accidents_Aboard_Merchant_Ships_Marine_Navigation_and_Safety_of_Sea_Transportation
15. Fan S, Blanco-Davis E, Yang Z, Zhang J, Yan X. Incorporation of human factors into maritime accident analysis using a data-driven Bayesian network. Reliab Eng Syst Saf. 2020;203:107070. Available from: https://doi.org/10.1016/j.ress.2020.107070
16. Mullai A, Paulsson U. A grounded theory model for analysis of marine accidents. Accid Anal Prev.

2011;43(4):1590-603. Available from: https://doi.org/10.1016/j.aap.2011.03.022

17. Uğurlu Ö, Erol S, Başar E. The analysis of life safety and economic loss in marine accidents occurring in the Turkish Straits. Marit Policy Manag. 2016;43(3):356-70. Available from: https://doi.org/10.1080/03088839.2014.1000992

18. Christofilea O, Farantos G, Psaridi L, Tsaousi M, Sartzi S, Dounias G. Assessment of workplace safety climate among healthcare workers: a case study of the public sector hospitals in Greece. Eur Sci J. 2025;21(37):146. Available from: https://doi.org/10.19044/esj.2025.v21n37p146

19. Karaiskos C, Vlastos I, Farantos G, Rachiotis G, Simou E, Dounias G. Chronic noise exposure with normal hearing is related to adverse quality of life and burnout. Eur Sci J. 2025;21(37):1. Available from: https://doi.org/10.19044/esj.2025.v21n37p1

20. Farantos G, Dounias G. Key performance indicators in occupational health and safety of hospitals: a scoping review with meta-analysis. G Ital Psicol Med Lav. 2024;4(1):12-26. Available from: https://doi.org/10.17605/OSF.IO/JA4R2

International Journal of Occupational Safety and Health

ISSN: 2091-0878 (Online) ISSN: 2738-9707 (Print)

Narrative Review

Microplastics in groundwater and their effects

Chamatzolas S[1]

[1] Department of Public Health Policy, University of West Attica, Athens, Greece.

Corresponding author:
Stelios Chamatzolas,
Environmental Engineer, University of West Attica, Athens.
E-mail:
chamatzolasstelioss@gmail.com
Tel.: +306957836042
ORCID ID: https://orcid.org/0009-0009-3815-3735

Date of submission: 06.12.2025
Date of acceptance: 04.04.2026
Date of publication: 15.04.2026

Conflicts of interest: None
Supporting agencies: University of West Attica, Athens

DOI:https://doi.org/10.3126/ijosh.v16i1.87155

Copyright: This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License

ABSTRACT

This paper is a narrative review on microplastics (MPs). The properties and behavior of MPs in the environment are emphasized, noting that they are groundwater pollutants, are harmful to biotic and abiotic environments, exhibit stable and unique chemical properties, and persist in the environment for prolonged periods. They are resistant to biodegradation, precipitate and accumulate in the bodies of microorganisms. The routes of exposure to MPs in work environments are highlighted, noting that deposition is the main route of human exposure to MPs. The risk assessment for MPs is implemented with the polymer hazard index ecological hazard index, the hazard quotient, and the ecological hazard quotient. The pollution load index, which is related to the microplastic concentration coefficient, and the MPs pollution risk index are utilized. The effects of MPs on humans are highlighted, the main ones being thyroid disorders, headaches, cardiovascular problems and obesity. The prevention and control of MPs pollution is mentioned through the Operation Clean Sweep program, which includes containment measures and employee awareness training. The new contributions of my narrative review are mentioned, which lie in strengthening research on the mechanisms of interactions of MPs with human health and the complete clarification of the organs in which inhaled particles are deposited. Another contribution is the elimination of biochar limitations such as the quantification of the dynamic accumulation of MPs in the environment.

Keywords: inflammation, inhalation, mitigation, risk

Introduction

Groundwater is an important source of water for various purposes, including drinking and agriculture. Groundwater maintains ecosystem health, supports aquatic habitats, and contributes to biodiversity. Groundwater is utilized in emergency situations, such as floods. The world's groundwater supply is a vital component for sustaining life on Earth. Groundwater quality reflects multiple environmental factors, both natural and anthropogenic. Groundwater quality assessment is crucial to safeguard public health and to improve the sustainability of groundwater resources. MPs are plastic debris with diameters less than 5 mm and various shapes, such as fibers and fragments.[1] The percentage of MPs in sizes 1–5 mm, 0.2–1 mm, 0.1–0.2 mm, and <0.1 mm were 16%, 26%, 29% and 29%, respectively.[2] MPs originate from thermal degradation, biodegradation and the degradation of plastic residues.[3] MPs enter the environment in two main ways: as primary MPs, used in personal care products, and as secondary MPs. The former have a defined and usually round shape and size. Primary MPs are used in blasting technology, which includes blasting acrylics, engines, and boat hulls to remove rust and paint. Secondary MPs originate from the decomposition of car tires and contain stabilizers and flame retardants.[4] They

originate from the chemical and biological processes of plastic particles. Exposure to sunlight causes the photodegradation of secondary MPs. The latter is caused by UV radiation promoting oxidation of the polymer matrix, leading to bond breakdown, fragmentation, and slow degradation. MPs have recently emerged as groundwater contaminants. MPs are harmful to biotic and abiotic environments. MPs on beaches have enhanced oxygen availability, resulting in rapid degradation and brittleness, forming cracks and "yellowing." The loss of structural integrity makes MPs susceptible to fragmentation resulting from abrasion, wave action, and turbulence. MPs can further degrade and become nanoplastics in size, although the smallest microparticle currently reported in the oceans is 1.6 μm in diameter. They pose a challenge to water safety due to their characteristics.[5] Inadequate occupational health facilities and services cause great human losses, harming the health, well-being and quality of life of workers. The use of personal protective equipment is a key element of workplace safety and an effective measure to protect workers' health from microplastics.[6]

The materials of MPs are polyethylene (PE), polyvinyl chloride (PVC), polystyrene (PS), polyethylene terephthalate (PET), polyamide (PA), and polypropylene (PP).7 PE, PET, PP and PVC alter anaerobic microbial communities in sludge and suppress methane production. PE is a widely produced polymer, often used in single-use plastics and synthetic fabrics, and is mainly released into the environment through wastewater disposal. PET is a flexible thermoplastic polymer commonly used in the manufacture of beverage bottles, food packaging and synthetic fabrics, and is distinguished by its strength and excellent gas barriers. PET is denser than water and tends to settle into sediment layers, where it can accumulate and pose a risk to benthic organisms.8 PET and PP are among the most widespread microplastics worldwide and are frequently detected in necropsied human lung tissue and myocardial tissue.[9] PP exhibits moderate abundance and mobility, and under certain hydrodynamic conditions, can accumulate in hot spots.[10] PA and PP have been shown to enhance sludge solubilization and hydrolysis, stimulate key enzymatic activities and, therefore, improve methane production.[11] PVC is used to manufacture medical devices and consumables due to its excellent chemical stability, optical transparency, and mechanical flexibility.[12] PS and PVC have been detected in human tear fluid, meibomian gland, and vitreous humor.[13] MPs exhibit stable and unique chemical properties and persist in the environment for prolonged periods. They are resistant to biodegradation, precipitate and accumulate in the bodies of microorganisms and persist throughout the food chain when consumed.[14] MPs are modified depending on temperature and pH.[15] The production of MPs has skyrocketed over the past eight decades to over 8.3 billion metric tons, with 80% of MPs being released into the environment. [16] MPs in the ocean amount to 12.7 million tons per year, with approximately 51 trillion microplastic particles in the ocean.[17] Annual MPs production amounts to over 280 million tons.[18] MPs production reached 348 million tons in 2017.[19]

Routes of exposure to microplastics in work environments: Wastewater treatment plants receive MPs from domestic and industrial wastewater, and MPs are widespread in urban wastewater.[20] The abundance of MPs in wastewater treatment plants can reach up to 3 × 104 particles/L.[21] MPs enter the human body through inhalation, ingestion, and skin contact.[22] The importance of microplastics entering the human body through ingestion of contaminated food or water is well documented by the fact that microplastics are detected in various foods.[23] Human exposure to MPs via ingestion is estimated at 0.1–5 g/week and fecal microparticle portion concentrations serve as a practical biomarker for assessing ingestion-based exposure, representing approximately 94% of total daily excreted portions.[24] Annual estimates of human consumption of MPs range from 39,000 to 52,000 particles, making dietary exposure the primary route for human interaction with MPs.[25] Factors that influence the transport and deposition of particles in the human airways are particle shape, density and concentration, flow regimes, airway geometry, breathing intensity and particle size. The latter two have the most significant effect on particle deposition.[26]

Recycling MPs can reduce carbon emissions by 30% to 80%, and chemical recycling can achieve a 50% reduction in climate change impacts by breaking MPs down into their basic building blocks through hydrolysis, pyrolysis, and gasification.[27] Mechanical recycling is used in primary and secondary processes and includes collection, sorting, washing, shredding and separation. PET, PE and PP are suitable for mechanical recycling. For PET, enzymatic degradation, a recycling method that uses esterases of the cutinase class, is preferred. Enzymes have an advantage over chemical

recycling due to their selectivity for specific depolymerization and leave other components unaffected.[28] PP recycling reduces plastic waste and greenhouse gas emissions while conserving mineral resources. Challenges remain regarding the degradation of mechanical properties and the variability in the quality of recycled PP. Effective recycling strategies are needed to maintain the material's performance.[29] Recycling PA by acidolysis achieves lower environmental impacts than conventional hydrolysis, highlighting its potential as a more sustainable recycling route. PA can be recycled using dicarboxylic acids to depolymerize it, creating recycled products that are used to produce new materials.[30] Nanotechnology has proven effective in combating MPs pollution and constitutes a strong technological basis for the design of materials for various application areas such as packaging and textiles. It is gaining increasing importance in our complex world and a growing number of applications are demonstrating its high-performance capability on a regular basis. Its unique ability to define materials and structures at the nanoscale opens up new opportunities to address some of the most pressing challenges.[31] The physicochemical properties of nanomaterials, their high surface-to-volume ratio, and tunable surface chemistry enable efficient adsorption, degradation, and separation of MPs, even at low concentrations.[32] Nanomaterials are incorporated into membrane technologies to improve their permeability, ensure safe recovery of nanomaterials, be much more reactive, and have higher uptake capacity compared to bulk materials. Carbon nanomaterials and nanocomposites catalyze photocatalytic degradation, selective adsorption, and antimicrobial activity. [33]

Routes of exposure to microplastics in work environments: Wastewater treatment plants receive MPs from domestic and industrial wastewater, and MPs are widespread in urban wastewater.[20] The abundance of MPs in wastewater treatment plants can reach up to 3 × 104 particles/L.[21] MPs enter the human body through inhalation, ingestion, and skin contact.[22] The importance of microplastics entering the human body through ingestion of contaminated food or water is well documented by the fact that microplastics are detected in various foods.[23] Human exposure to MPs via ingestion is estimated at 0.1–5 g/week and fecal microparticle portion concentrations serve as a practical biomarker for assessing ingestion-based exposure, representing approximately 94% of total daily excreted portions.[24] Annual estimates of human consumption of MPs range from 39,000 to 52,000 particles, making dietary exposure the primary route for human interaction with MPs.[25] Factors that influence the transport and deposition of particles in the human airways are particle shape, density and concentration, flow regimes, airway geometry, breathing intensity and particle size. The latter two have the most significant effect on particle deposition.[26]

Recycling MPs can reduce carbon emissions by 30% to 80%, and chemical recycling can achieve a 50% reduction in climate change impacts by breaking MPs down into their basic building blocks through hydrolysis, pyrolysis, and gasification.[27] Mechanical recycling is used in primary and secondary processes and includes collection, sorting, washing, shredding and separation. PET, PE and PP are suitable for mechanical recycling. For PET, enzymatic degradation, a recycling method that uses esterases of the cutinase class, is preferred. Enzymes have an advantage over chemical recycling due to their selectivity for specific depolymerization and leave other components unaffected.[28] PP recycling reduces plastic waste and greenhouse gas emissions while conserving mineral resources. Challenges remain regarding the degradation of mechanical properties and the variability in the quality of recycled PP. Effective recycling strategies are needed to maintain the material's performance.[29] Recycling PA by acidolysis achieves lower environmental impacts than conventional hydrolysis, highlighting its potential as a more sustainable recycling route. PA can be recycled by depolymerizing it with dicarboxylic acids, creating recycled products that are used to produce new materials.[30] Nanotechnology has proven effective in combating MPs pollution and constitutes a strong technological basis for the design of materials for various application areas such as packaging and textiles. It is gaining increasing importance in our complex world and a growing number of applications are demonstrating its high-performance capability on a regular basis. Its unique ability to define materials and structures at the nanoscale opens up new opportunities to address some of the most pressing challenges.[31] The physicochemical properties of nanomaterials, their high surface-to-volume ratio, and tunable surface chemistry enable efficient adsorption, degradation, and separation of MPs, even at low concentrations.[32] Nanomaterials are incorporated into membrane technologies to improve their

permeability, ensure safe recovery of nanomaterials, be much more reactive, and have higher uptake capacity compared to bulk materials. Carbon nanomaterials and nanocomposites catalyze photocatalytic degradation, selective adsorption, and antimicrobial activity.[33]

Risk assessment of microplastics: The risk of MPs is significant due to their easy transport by winds and the longevity of polymeric structures.[34] The risk assessment is implemented based on the polymer hazard index, the ecological risk index, the hazard quotient and the ecological risk quotient. The latter two are advantageous because they incorporate species sensitivity distributions and probabilistic diversity adjustments to prioritize global mitigation. Comprehensive ecological risk assessment requires integrating particle size, shape, density, polymer hazard, abundance, and mass concentration. Assessing the ecological risks of microplastics remains difficult due to methodological inconsistencies in detection.[35] The pollution load index for each station is related to the MPs concentration factor. An index value less than 10 represents the minimum risk and an index value greater than 30 represents the highest risk.[36] The microplastic pollution risk index was developed to describe the multidimensional risk profile of microplastics by incorporating factors such as shape, size, color, and polymer durability. It incorporates the characteristics of the polymer's risk, abundance, size, and color.[37] The most reliable quantitative risk-based thresholds for ecosystems still contain moderate to high uncertainties. The main source of uncertainty in assessing the risk of microplastics to the biosphere stems from their multifaceted nature, such as size, shape, polymer type, and the presence of chemical additives. The development of harmonized assessment methodologies and benchmarks, together with enhanced research, holds significant promise for strengthening confidence in risk thresholds with more reliable conclusions.[38] The risk assessment of MPs in natural processes refers to their environmental burden, which is enhanced by photoaging by altering the adsorption capacity of microplastics to pollutants. Photoaged MPs have a higher risk of human exposure.[39]

Impact of microplastics on workers: MPs agents have harmful effects on human health, as they release harmful additives, degrade the environment, are involved in ecological hazards and cause toxicological effects.[40] The effects of microplastics include oxidative stress, DNA damage, and can disrupt the gut microbiome, causing dysbiosis.[41] Exposure to MPs causes limited larval body length, reduced heart rate, and disturbances in redox homeostasis.[42] Sol et al.'s study reported that MPs have the potential to obstruct the digestive tracts of aquatic organisms by releasing harmful compounds.[43] MPs cause mental disorders, headaches and are implicated in developmental disorders and hyperactivity.[44] Health impacts include thyroid disorders, obesity and diabetes and are exploited as habitats for disease-carrying insects and pathogenic bacteria.[45] The study by Pauly et al. documented that human exposure to MPs causes acute and chronic lung inflammation.[46] MPs agents have negative effects on the human endocrine system, as phthalates and bisphenol-A modify it, causing metabolic disorders.[47] Winiarska et al.'s study points out that ingestion of MPs particles through food has been associated with cancer risk in humans.[48] Ingestion of MPs particles causes pathological stress, false satiety and inhibition of enzyme production.[49] PS-MPs inhibit the function of catalase, which disrupts the activity of superoxide dismutase and glutathione peroxidase.[50] PS and PVC are associated with functional impairments of the respiratory, gastrointestinal, reproductive and immune systems, causing damage to corneal tissue. Exposure to PS/PVC causes inflammation of the ocular surface through mitochondrial damage and disruption of lipid metabolism.

Microplastics prevention and control: The prevention and control of MP pollution include the adoption or promotion of best available techniques, as reflected in integrated environmental permitting. The Operation Clean Sweep program includes implementing actions to minimize risks, such as containment measures and a training program to raise employee awareness. New containment measures can be introduced in the MPs processing and management industry, including mandatory pre-treatment of stormwater. New industries should create separate sewage systems and incorporate wastewater treatment, independent of wastewater treatment. As a pretreatment system for stormwater that is likely to carry MPs, a hydrocarbon separation-decantation unit is recommended. It retains settling and floating particles before their discharge into watercourses or the general drainage network of the industrial zone. The design of hydrocarbon separation-decantation systems could be optimized and adapted to specifically address the retention of MPs from industrial sources.[51]

Regulations, guidelines, gaps and future lines of research on microplastics: The European Union aims to reduce MPs releases by 30% by 2030, focusing on limiting the use of intentionally added MPs in products and minimizing unintentional releases of MPs. There is no comprehensive EU legislation specifically addressing MPs. Some targets are covered by the European Chemicals Agency restriction proposal, which targets intentionally added MPs, which unfortunately account for 5% of total plastic.[52] For MPs, the European Union has issued the Single-Use Plastics Directive, the Waste Framework Directive, the Packaging and Packaging Waste Directive, and the Marine Strategy Framework Directive.[53] Global legislation aims to manage the risks and impacts of plastic bag litter with strategies such as levies and bans. The latter have effectively controlled pollution by MPs at the regional level, particularly reducing the use of low-density PE bags.[54] The 2019 European Union directive on single-use plastics and combating their impact on the environment includes the withdrawal of single-use plastic products such as cutlery, plates, straws, cotton buds and drink stirrers. Sticks that attach to and support balloons and their mechanisms, products made of Oxo-degradable plastic, beverage and food containers, and expanded polystyrene cups, lids, and covers are withdrawn. The directive sets a 90% collection target for all single-use plastic bottles by 2029.[55] The 2018 European Union directive includes measures to prevent packaging waste and promote reuse and recycling. The directive covers all packaging placed on the market and all packaging waste. Member States must ensure that packaging placed on the market can be reused or recovered. The European Commission is examining ways to improve packaging design to enable reuse and promote high-quality recycling, thereby achieving the targets. The latter includes achieving that by 31 December 2025, at least 65% by weight of all packaging waste must be recycled. By 31 December 2030, at least 70% by weight of all packaging waste must be recycled.[56]

The urgent need for further research on MPs is underlined by the need to understand the mechanisms of interactions of microorganisms with human health and to develop effective regulatory measures. It is still unclear where inhaled particles are deposited in the respiratory tract by the complex agents. Accurate prediction of deposition patterns is important to facilitate clinicians in monitoring patient health and managing risks associated with MPs exposure.[57] Knowledge gaps limit our ability to manage MP-related pollution in deltaic systems. This is due to the fragmented focus of existing studies, which often examine MPs in isolation from sediment processes, metal interactions, or land-use feedbacks. There is insufficient evidence for the accumulation of MPs in floodplains, particularly those used for agriculture, despite their frequent flooding and exposure.[58] Biochar can remove MPs, but several challenges prevent its large-scale application. One challenge lies in understanding how variations in the algae feedstock affect the final properties of the biochar. Another challenge is developing strategies to preserve useful elements such as nitrogen, oxygen and sulfur during production at high temperatures.[59] Traditional MPs extraction methods present difficulty in monitoring dynamic molecular events executed by MPs and inability to uncover unknown signaling interaction networks. Traditional models are difficult to quantify the dynamic accumulation of MPs in the microenvironment. In vitro cell experiments cannot simulate the complexity of cell-matrix interactions. It is difficult to accurately detect low-concentration, small-sized micro particles, and the sample pretreatment steps are complex and prone to loss. Future research lies in developing a method that will eliminate the above difficulties to enable the effective removal of MPs.[60] Coral reefs are not exposed to single pollutants and toxicity experiments must include mixtures of MPs of different polymers, sizes and shapes as a function of pH, temperature and chemical pollutants.[61]

Discussion

My narrative review concerns MPs that originate from thermal degradation and the degradation of plastic residues, enter the environment as primary MPs and as secondary MPs and pose a challenge to water safety due to their characteristics. The production of MPs has skyrocketed over the last eight decades to over 8.3 billion metric tons, their annual production amounts to over 280 million tons, and their production skyrocketed to 348 million tons in

2017 (table 1). The abundance of microplastics in wastewater treatment plants reaches 3 × 104 particles/L. Human exposure to MPs through ingestion is estimated at 0.1-5 g/week with annual consumption ranging from 39,000 to 52,000 particles. Recycling of MPs has the potential to reduce carbon emissions by 30% to 80%, and chemical recycling achieves a 50% reduction in climate change impacts. It is noted that the MPs risk assessment is done with the pollution load index where an index value less than 10 represents the minimum risk and an index value greater than 30 represents the highest risk. The most reliable quantitative risk thresholds for ecosystems continue to contain moderate to high uncertainties with their main sources being size, shape, polymer type and the presence of chemical additives. The release of harmful additives, the induction of toxicological effects, oxidative stress and inhibition of enzyme production are reported, highlighting the effects of MPs on humans. Prevention and control of MPs pollution includes the implementation of mandatory pre-treatment of stormwater by improving the design of hydrocarbon separation-deposition systems. The European Union aims to reduce MPs by 30% by 2030. The European Union directive sets a 90% collection target for all single-use plastic bottles by 2029. The European Commission promotes the achievement, by 31 December 2025, of at least 65% by weight of all packaging waste being recycled and by 31 December 2030, of at least 70% by weight of all packaging waste being recycled. The need to overcome difficulties such as nitrogen, oxygen and sulfur conservation and monitoring dynamic molecular events with the inability to uncover unknown signaling interaction networks is emphasized in order to strengthen the effectiveness of biochar.

Table 1: Illustration of microplastic production in the period 1950-2017 and the future estimate for 2050 and 2060.

	1950	2010	2017	2050	2060
Microplastic production (million tons)	2	275	348	600	155-265

Conclusion

MPs enter the human body through inhalation, ingestion and skin contact, and the factors that influence particle deposition in the human airways are the shape, density and concentration of the particles and the intensity of breathing. The risk of microplastics is high due to their easy transport by winds and the longevity of polymeric structures. Assessing the risk of microplastics remains difficult due to methodological inconsistencies in detection. The development of harmonized assessment methodologies, combined with enhanced research, promises to strengthen confidence in risk thresholds and in reliable conclusions. MPs cause DNA damage, mental and developmental disorders, lung inflammation and cancer. PS and PVC cause damage to corneal tissue and disruption of lipid metabolism. Prevention and control of MPs pollution is achieved by creating separate sewage systems for new industrial developments and a hydrocarbon separation-dewatering unit is recommended for a pre-treatment system for rainwater. Biochar has the potential to remove MPs, and it is difficult to accurately detect low concentrations and small-sized MPs, with the sample pretreatment steps being complicated.

References

1. Chen G, Zou Y, Xiong G, Wang Y, Zhao W, Xu X, et al. Microplastic transport and ecological risk in coastal intruded aquifers based on a coupled seawater intrusion and microplastic risk assessment model. Journal of Hazardous Materials. 2024;480:135996. Available from: https://doi.org/10.1016/j.jhazmat.2024.135

2. Mirzabayati F, Hamidian AH. Investigating the Effect of Plant Presence and Leachate Irrigation on the Distribution of Microplastics in Different Soil Depths and the Rhizosphere. Results in Engineering. 2025;28:107740. Available from: https://doi.org/10.1016/j.rineng.2025.107740

3. Pham TV, Doan TD, Vu SV, Nguyen QD, Lo TNH, Park I, et al. Fast and facile controlled synthesis of silver nanocubes using the solvothermal process to create SERS substrates for detecting polystyrene microplastics. Journal of Physics and Chemistry of Solids. 2026;208:113196. Available from: https://doi.org/10.1016/j.jpcs.2025.113196

4. Wei Z, Wei T, Chen Y, Zhou R, Zhang L, Zhong S. Seasonal dynamics and typology of microplastic pollution in Huixian karst wetland groundwater: Implications for ecosystem health. Journal of Environmental Management. 2024;358:120882. Available from: https://doi.org/10.1016/j.jenvman.2024.120882

5. Omotola EO, Supriyanto G. Occurrence, detection and ecotoxicity of microplastics in selected environments-a systematic appraisal. Heliyon. 2024;10(14):e32095. Available from: https://doi.org/10.1016/j.heliyon.2024.e32095

6. Joshi M, Dhakal G, Shrestha S, et al. Occupational health problems, workplace environment and utilization of personal protective equipment among welders of Banepa Municipality, Nepal. International Journal of Occupational Safety and Health. 2020;10(2):100-7. Available from: https://doi.org/10.3126/ijosh.v10i2.30175

7. Guo J, Huang XP, Xiang L, Wang YZ, Li YW, Li H, et al. Source, migration and toxicology of microplastics in soil. Environment International. 2020;137:105263. Available from: https://doi.org/10.1016/j.envint.2019.105263

8. Salama WM, El-Shafai NM, El-Wakeil AS, Shukry M, El-Mehasseb IM, Tayelet AA et al. Promising eco-friendly nanocomposite materials to remove microplastic pollutants from the aquatic system and following their effect on the biological parameters of crayfish. Inorganic Chemistry Communications. 2025;183:115775. Available from: https://doi.org/10.1016/j.inoche.2025.115775

9. Lee Y, Heo S, Park K, Noh Y, Kim D, Kimet M et al. Potential risk of aromatic microplastic fragments during urinary excretion. Journal of Hazardous Materials. 2025;501:140710. Available from: https://doi.org/10.1016/j.jhazmat.2025.140710

10. Xie Q, Lin X, Tan L, Luo L, Luo S, Tian X et al. Removal of polypropylene microplastics from water by microalgae Desmodesmus sp.: Influences, kinetics and mechanisms. Algal Research. 2026;94:104539. Available from: https://doi.org/10.1016/j.algal.2026.104539

11. Xiao Y, Liu Y, Zhou J, Jiang X, Gao P. Deciphering dose-dependent effects of polypropylene and polyethylene microplastics on digestion performance dynamics and antibiotic resistance development in sludge anaerobic digesters. Chemical Engineering Journal. 2025;527:172044. Available from: https://doi.org/10.1016/j.cej.2025.172044

12. Yan L, Wang B, Zhao R, Yang Z, Wu X, Shi L. Branched Fluoro-polyether copolymer for constructing polyvinyl chloride composites with reinforced antibiofouling performance. Reactive and Functional Polymers. 2025;219:106586. Available from: https://doi.org/10.1016/j.reactfunctpolym.2025.106586

13. Wen B, Ma B, Tao H, Chen S, Zhang J, Shi M, et. al. Polystyrene and Polyvinyl Chloride Microplastics Exposure Induces Ocular Surface Inflammation by Causing Mitochondrial Damage and Lipid Metabolic Disruption. Journal of Hazardous Materials. 2026;502:140995. Available from: https://doi.org/10.1016/j.jhazmat.2025.140995

14. Shu Q, Xie S, Junaid M, Zheng R, Tang H, Zou J, et. al. MPs and PFOS single and combined exposure significantly alter genetic expressions of growth hormone and insulin growth factor-related biomarkers during zebrafish embryonic development. Science of The Total Environment. 2024;949:174925. Available from: https://doi.org/10.1016/j.scitotenv.2024.174925

15. Xumiao L, Prata JC, Costa JP, Duarte AC, Rocha-Santos T, Cerqueira M et al. Collection and separation analysis of airborne microplastics. Comprehensive Analytical Chemistry. 2023;100:33-61. Available from: https://doi.org/10.1016/bs.coac.2022.07.003

16. Assis GC, Antonelli R, Dantas AOS, Teixeira ACSC. Microplastics as hazardous pollutants: occurrence, effects, removal and mitigation by using plastic waste as adsorbents and supports for photocatalysts. Journal of Environmental Chemical Engineering. 2023;11(6):111107. Available from: https://doi.org/10.1016/j.jece.2023.111107

17. Zhu J, Yang K, Zhong Y, Pi P. Piezoelectricity-enhanced Janus membranes with superior antifouling properties for high-efficiency separation of microplastics. Separation and Purification Technology. 2025;380:135275. Available from: https://doi.org/10.1016/j.seppur.2025.135275

18. Sezer M, Topkaya E, Aksan S, Veli S, Arslan A. Optimizing microplastic treatment in the effluent of biological nutrient removal processes using electrocoagulation: Taguchi experimental design. Journal of Environmental Management. 2024;369:122413. Available from: https://doi.org/10.1016/j.jenvman.2024.122413

19. Xu S, Ma J, Ji R, Pan K, Miao AJ. Microplastics in aquatic environments: occurrence, accumulation, and biological effects. Science of the total environment. 2020;703:134699. Available from: https://doi.org/10.1016/j.scitotenv.2019.134699

20. Sanjeev NO, Vallabha MS, Rabi RRL. Nanotechnology-based approaches for the removal of microplastics from wastewater: a comprehensive review. Beilstein Journal of Nanotechnology. 2025;16(1):1607-32. Available from: https://doi.org/10.3762/bjnano.16.114

21. Salih WY, Hassan FM, Sabbah MA. Microplastics toxicity: Classification, sources, exposure routes, and experiments. Desalination and Water Treatment. 2026;325:101599. Available from: https://doi.org/10.1016/j.dwt.2025.101599

22. Jin Y, Li X, Cheng X, Chen K, Mu R. Particle size matters: Unraveling the impact of microplastic heteroaggregates on algal–bacterial consortium in wastewater treatment. Journal of Environmental Chemical Engineering. 2025;13(5):117819. Available from: https://doi.org/10.1016/j.jece.2025.117819

23. Adjama I, Dave H. Quantitative and qualitative assessment of microplastics contamination in plastic-wrapped candies and estimation of dietary exposure in early childhood. Science of The Total Environment. 2026;1013:181345. Available from: https://doi.org/10.1016/j.scitotenv.2026.181345

24. Kao CS, Jiang CB, Yang CC, Wang YL, Chen YH, Chao HJ, et al. Combined exposure to microplastics and cadmium alters gut microbiota composition in preschool children: a cross-sectional study. Journal of Hazardous Materials. 2025;501:140854. Available from: https://doi.org/10.1016/j.jhazmat.2025.140854

25. Beegam S, Al-Salam S, Zaaba NE, Elzaki O, Greish YE, Ali BH et al. Polystyrene microplastics exacerbate experimental chronic kidney disease via inflammatory and oxidative pathways involving NF-κB, ERK/p38 MAPK, and sirtuin-1. Life Sciences. 2026;385:124142. Available from: https://doi.org/10.1016/j.lfs.2025.124142

26. Adnan M, Kampeewichean C, Tanprasert S, Korkerd K, Piumsomboon P, Tipratchadaporn S, et al. CFD modeling of particle deposition in human airways: Effect of inhalation rate, body temperature, and relative humidity. Particuology. 2026;108:99-112. Available from: https://doi.org/10.1016/j.partic.2025.11.001

27. Alabi OO, Akande TO, Gbadeyan OJ, Deenadayaluc N. Advanced technologies for plastic waste recycling: examine recent developments in plastic waste recycling technologies. RSC advances. 2025;15(48):40541-57. Available from: https://doi.org/10.1039/d5ra06715d

28. Harings JMW, Ballerstedt H, Blank LM. Recycling-privileged plastic polymers. Current Opinion in Green and Sustainable Chemistry. 2025;56:101049. Available from: https://doi.org/10.1016/j.cogsc.2025.101049

29. Barros D, Leite F, Bessa J, Carneiro V, Barbosa JP, Fangueiro R. Impact of reprocessing cycles and chain extender on recycled polypropylene properties. Next Materials, 2026, 11: 101622. Available from: https://doi.org/10.1016/j.nxmate.2026.101622

30. Gama N, Penzo D, Godinho B, Rossignolo G, Quinteiro P, Dias AC et al. Rethinking Nylon Recycling: A Novel Chemical Approach for Sustainable Polyamide Valorization. Journal of Environmental Chemical Engineering. 2026;14(1):120988. Available from: https://doi.org/10.1016/j.jece.2025.120988

31. Gellermann C, Haas KH, Hagendorf C, Laux P, Luch A, Miclea PT, et al. Key examples of nanotechnology in microplastics, packaging and textiles. Next Research. 2026;4:101252. Available from: https://doi.org/10.1016/j.nexres.2025.101252

32. Sharma AK; Choudhary A, Chauhan P, Chaliha J. Nanomaterials for the remediation of microplastics in wastewater. Nano Trends. 2025;12:100152. Available from: https://doi.org/10.1016/j.nwnano.2025.100152

33. Baba IA, Mustapha S, Abdulkareem AS, Tijani JO, Obayomi KS. Emerging nanotechnologies for paint wastewater treatment: Trends, challenges, and sustainable solutions. Environmental Research. 2026;294:123819. Available from: https://doi.org/10.1016/j.envres.2026.123819

34. Golmohammadi M, Musavi SF, Habibi M, Maleki R, Golgoli M, Zargar M, et al. Molecular mechanisms of microplastics degradation: A review. Separation and Purification Technology. 2023;309:122906. Available from: https://doi.org/10.1016/j.seppur.2022.122906

35. Mei W, Li J, Ding X, Liu S, Qin S, Wang X et al. Comparative analysis of microplastics in aquatic environments: Matching thresholds, abundance versus mass concentration, and risk assessment. Environmental Pollution. 2026;392:127655. Available from: https://doi.org/10.1016/j.envpol.2026.127655

36. Savucaa A, Jijiec R, Chelarua IA, Ciobicad A, Nicoara MN. An analysis of the current and forecasted ecological risk related to the presence of microplastics on the Romanian Black Sea coast. Heliyon. 2026;12(1):e44291. Available from: https://doi.org/10.1016/j.heliyon.2025.e44291

37. Tajwar M, Muntaha S, Ashraf A, Islam MS, Saha SK. Polymer-Specific Hazard Profiling and Risk Indexing of Microplastics in Coastal Sediments of St. Martin's Island: A Multivariate and Machine Learning Approach. Journal of Hazardous Materials Advances. 2026;21:101017. Available from: https://doi.org/10.1016/j.hazadv.2026.101017

38. Kennedy SB, Vital ALA, Kukkola A, Miller E, Yeh A, Coffin S et al. Trends in Quality and Risk Assessment Applicability of Microplastic Ecotoxicity Studies. Journal of Hazardous Materials Advances. 2026;21:100942. Available from: https://doi.org/10.1016/j.hazadv.2025.100942

39. Tong J, He S, Huang X, Li X, Nie X, Li Z, et al. The fate, impacts and potential risks of photoaging process of the microplastics in the aqueous environment. Journal of Contaminant Hydrology. 2025;275:104699. Available from: https://doi.org/10.1016/j.jconhyd.2025.104699

40. Lalrinfela P, Vanlalsangi R, Lalrinzuali K, Babu PJ. Microplastics: Their effects on the environment, human health, and plant ecosystems. Environmental Pollution and Management. 2024;1:248-59 Available from: https://doi.org/10.1016/j.epm.2024.11.004

41. Elawady A, Mohamed JAH, Abid MB. Advancements in Microplastics Detection Techniques and Their Multidimensional Impacts on Aquatic Ecosystems and Human Health. Journal of Hazardous Materials: Plastics. 2026;2:100025. Available from: https://doi.org/10.1016/j.hazmp.2025.100025

42. Nawab A, Ahmad M, Khan MT, Nafees M, Khan I, Ihsanullah I. Human exposure to microplastics: A review on exposure routes and public health impacts. Journal of Hazardous Materials Advances. 2024,16:100487. Available from: https://doi.org/10.1016/j.hazadv.2024.100487

43. Šoša I, Labinac L, Perković M. Metabolic Dysfunction-Associated Steatotic Liver Disease Induced by Microplastics: An Endpoint in the Liver–Eye Axis. International journal of molecular sciences. 2025;26(7):2837. Available from: https://doi.org/10.3390/ijms26072837

44. Arcuri S, Pennarossa G, Bebbere D, Gandolfi F, Ledda S, Brevini TAL. Microplastic exposure induces epithelial barrier alterations and increases collagen deposition in a 3D human endometrial model in vitro. Journal of Assisted Reproduction and Genetics. 2025;42:3065-77. Available from: https://link.springer.com/article/10.1007/s10815-025-03566-7

45. Gong X, Tian L, Wang P, Wang Z, Zeng L, Hu J. Microplastic pollution in the groundwater under a bedrock island in the South China sea. Environmental Research. 2023;239:117277. Available from: https://doi.org/10.1016/j.envres.2023.117277

46. Garshasbi F, Miraki SK, Jokar Z, Maity A, Ramavandi B. Quantitative assessment and spatial distribution of macroplastic and cigarette butt contamination in Bushehr's stormwater system near the sensitive Persian Gulf coast. Marine Pollution Bulletin. 2026;222:118839. Available from: https://doi.org/10.1016/j.marpolbul.2025.118839

47. Shahsavari S, Adergani BA, Shafaroodi H, Akbari N, Basaran B, Sadighara M, et al. A systematic review on the effect of microplastics on the hypothalamus-pituitary-ovary axis based on animal studies. Toxicology Letters. 2025;413:111745. Available from: https://doi.org/10.1016/j.toxlet.2025.111745

48. Zangene S, Morovvati H, Anbara H, Khan MAH, Goorani S. Polystyrene microplastics cause reproductive toxicity in male mice. Food and Chemical Toxicology. 2024;194:115083. Available from: https://doi.org/10.1016/j.fct.2024.115083

49. Wang L, Chen A, Cui P, Zhang J, Wang D, Li Q. Regulating polyamide layer structure via hydroxylated multi-walled carbon nanotubes for high-flux nanofiltration membranes. Applied Surface Science. 2026;718:164810. Available from: https://doi.org/10.1016/j.apsusc.2025.164810

50. Obukohwo OM, Abodunrin OA, Ejiro OP, Rume RA, Edesiri TP. Lycopene supplement mitigates polystyrene microplastics (PS-MPs)-induced reproductive alteration in rats via modulation of steroidogenic enzymes, inhibition of apoptosis and oxido-inflammatory reaction. Kuwait Journal of Science. 2024;51(3):100244. Available from: https://doi.org/10.1016/j.kjs.2024.100244

51. Mendoza A, García-Noblia A, Peña-Rodríguez C. Prevention and control strategies for non-regulated industrial microplastic spills. Marine Pollution Bulletin. 2026;225:119271. Available from: https://doi.org/10.1016/j.marpolbul.2026.119271

52. An official website of the European Union, Preventing plastic grain losses to reduce microplastic pollution. 2025. Available from: http://data.europa.eu/eli/reg/2025/2365/oj

53. Zielli SO, Pascali JP, Mazzotti A, Fais P, Fini M, Faldini C, et al. Microplastics and Nanoplastics in human tissues: systematic review of evidence, analytical protocols, and methodological challenges. Talanta Open. 2026;13:100615. Available from: https://doi.org/10.1016/j.talo.2026.100615

54. Zeb A, Liu W, Ali N, Shi R, Wang Q, Wang J, et al. Microplastic pollution in terrestrial ecosystems: Global implications and sustainable solutions. Journal of hazardous materials. 2024;461:132636. Available from: https://doi.org/10.1016/j.jhazmat.2023.132636

55. An official website of the European Union. Single-use plastics and combating environmental impacts. 2022. Available from: http://data.europa.eu/eli/dir/2019/904/oj

56. An official website of the European Union, Packaging and packaging waste. 2025. Available from: http://data.europa.eu/eli/dir/1994/62/oj

57. Kang P, Zhao Y, Ji B, Cai Y, Sun Y, Wang Z. The fate of microplastics/nanoplastics (MPs/NPs) in constructed wetlands: Addressing methodological gaps and experimental challenges from lab-scale to full-scale. Journal of Hazardous Materials. 2025;499:140287. Available from: https://doi.org/10.1016/j.jhazmat.2025.140287

58. Islam MA, Hoque MA, Couceiro F, Fowler M. Microplastic dynamics and land contamination in deltaic environments-A systematic review of current understanding and knowledge gaps. Environmental Pollution. 2025;389:127396. Available from: https://doi.org/10.1016/j.envpol.2025.127396

59. Mohanty A, Behera M, Dash AK, Verma AK. Microalgae - Derived Biochar for Microplastic Removal from Aquatic Systems: A Comprehensive Review and Future Perspectives. Regional Studies in Marine Science. 2026;94:104767. Available from: https://doi.org/10.1016/j.rsma.2026.104767

60. Sun Y, Zhang Y, Wang Y, Wang K, Wang Z, Wei Z, et al. From accumulation to degeneration: Microplastics as emerging risk factors for intervertebral disc health. Environmental Pollution. 2025;388:127379. Available from: https://doi.org/10.1016/j.envpol.2025.127379

61. Slynkova N, Leusch FDL, Pitt KA, Hoogenboom MO, Ziajahromi S. A systematic review of microplastics in coral reef ecosystems: Abundance, distribution, toxicity, and future research directions. Marine Pollution Bulletin. 2026;223:119010. Available from: https://doi.org/10.1016/j.marpolbul.2025.119010

International Journal of Occupational Safety and Health

ISSN: 2091-0878 (Online) ISSN: 2738-9707 (Print)

Review Article

Occupational hazards among food delivery workers: a systematic review of empirical studies

Ziaka V[1], Mavropoulos P[2], Koupidis S[3], Rachiotis G[4], Vitale E[5], Dounias G[6]

[1]Spec Occupational Physician, MS in Occupational and Environmental Health, Greece, [2] Interbalkan Medical Center, Greece, [3]Occupational Physician, Lecteur in Occupational and Environmental Health, Greece, [4]Professor of Epidemiology and Occupational Hygiene Department, Faculty of Medicine, University of Thessaly, Greece, [5]Assistant Professor in Occupational Medicine at the University of Enna, Italy, [6]Professor in Occupational Medicine at the University of West Attica, Greece.

Corresponding author:
Ziaka Varvara
Spec Occupational Physician, MS in Occupational and Environmental Health, Greece.
E-mail: ziakarenia@gmail.com
Tel.: +306945354874
ORCID ID: https://orcid.org/0009-0002-0323-7700

Date of submission: 30.11.2025
Date of acceptance: 05.04.2026
Date of publication: 15.04.2026

Conflicts of interest: None
Supporting agencies: Department of Occupational Medicine, University of West Attica, Greece.
DOI: https://doi.org/10.3126/ijosh.v16i1.87002

Copyright: This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License

ABSTRACT

Introduction: The rapid growth of e-commerce has driven the global expansion of food delivery services. Delivery riders are exposed to multiple occupational hazards due to time pressure, long working hours, and physically demanding tasks. Despite their essential role, research on their health and safety remains fragmented.

Methods: This review followed the PRISMA 2020 guidelines. A systematic search was conducted in the MEDLINE and Scopus databases. Only cross-sectional studies involving adult food delivery workers were included. Studies focusing on any type of accident or work-related health problem were considered. Other study designs, such as systematic reviews, were excluded. Studies involving non-food delivery workers or participants under 18 years of age were also excluded. The search was conducted only in English. Keywords and phrases such as "work," "accidents," and "delivery rider" were used with Boolean operators. The methodological quality of the included studies was assessed using the Joanna Briggs Institute (JBI) Critical Appraisal Checklist for Prevalence Studies.

Results: Occupational hazards were grouped into four categories. Traffic risks included speeding, running red lights, and mobile phone use while driving, with younger and less experienced riders showing a higher risk of accidents. Ergonomic risks were associated with prolonged sitting, vibration exposure, and repetitive movements, contributing to musculoskeletal disorders, particularly in the lower back, neck, and shoulders. Psychosocial risks included stress, burnout, verbal or physical abuse, and job insecurity. Socioeconomic factors, such as dependence on delivery income and lower educational levels, further increased vulnerability and limited access to preventive measures.

Conclusion: Food delivery workers face multidimensional risks that affect physical health, mental well-being, and road safety. Addressing these challenges requires comprehensive interventions, including road safety training, ergonomic improvements, psychosocial support, protective equipment, and improved working conditions to reduce accidents and protect worker health.

Keywords: Food Delivery Riders, Musculoskeletal Disorders, Occupational Safety, Psychosocial Stress, Traffic Accidents

Introduction

In recent years, the rapid growth of e-commerce has significantly increased demand for food delivery services, spurring the expansion of food delivery platforms. Various mobile applications allow customers to place online orders for food

and other goods. These orders are delivered via delivery services within a specific timeframe, and delivery riders play a crucial role in the online-to-offline service chain.

For example, China has the largest on-demand food delivery industry in the world, with a market size of 66.4 billion dollars in 2022 and nearly 13 million workers employed as delivery riders in 2021.[1]

However, concerns about dangerous driving and accidents among food delivery riders are steadily increasing, as traffic accidents worldwide have been steadily rising in recent years. Driving accounts for the largest portion of their working hours, and activities such as frequent stair climbing further increase their physical workload. Since they are paid per order assigned to them, their earnings depend on the number of deliveries completed and the distance of each route. Because each order is subject to strict time constraints and potential penalties for late delivery, riders feel pressured to minimize travel time and plan optimal delivery routes. All these factors lead to increased stress and mental workload during their work.[2] Previous research published in the International Journal of Occupational Safety and Health has also emphasized the importance of occupational safety measures and preventive strategies in reducing workplace accidents and improving worker safety.[3]

Similar findings have been reported in studies published in the International Journal of Occupational Safety and Health, where researchers identified time pressure, fatigue, and unsafe riding practices as important factors affecting the safety behavior of delivery riders and other transport workers.[4]

A study conducted among 563 platform delivery workers in Brazil showed that 44.1% had been involved in a work-related accident within the past year, 82.8% of which were traffic related. These rates were higher among younger workers (54.6% for those aged up to 28 years), and one in two reported working seven days a week.[5]

According to data from the U.S. Bureau of Labor Statistics (BLS), in the United States, there were 83 fatal incidents among professional drivers (including food delivery riders) in 2019, 72.3% of which were due to traffic accidents. In the same year, 8020 non-fatal injuries were recorded, resulting from falls, road collisions, or improper lifting of loads.

Furthermore, studies on platform workers show that those who rely entirely on platform work for their income are 1.36 times more likely to experience assault or threats compared to those who work part-time.[6] In a 2024 study conducted in India, it was found that 28% of delivery workers had experienced economic abuse (such as non-payment), 59% had faced verbal abuse, and 13% had suffered both forms of mistreatment. Data from systematic reviews reveal that delivery workers are exposed to high psychological stress due to unstable income and the lack of social protection. Similar findings have been reported in occupational health studies, which indicate that demanding working conditions and work-related stress can negatively affect workers' well-being and safety performance.[7] As a result, they experience anxiety and occupational burnout, which in turn increases the likelihood of accidents and assaults.[8]

Despite the significant growth in food delivery work in recent years, the available literature on the health and safety of delivery workers remains fragmented and often focuses on isolated aspects of the phenomenon. Conducting a systematic review is therefore deemed essential, as it enables the collection, evaluation, and synthesis of existing research data in a structured and evidence-based manner. Through this process, it becomes possible to highlight the most important risk factors, to map their impacts on food delivery workers' health and quality of life, and to identify knowledge gaps that require further investigation.

Such a review not only contributes to the scientific understanding of the issue but also

has significant practical implications. It can serve as a reference point for developing targeted prevention and intervention strategies, as well as for designing public health and occupational safety policies that enhance the safety, well-being, and sustainability of delivery workers. In this way, the systematic review becomes an indispensable tool for both the scientific community and policymakers, promoting a more comprehensive and evidence-based approach to addressing occupational risks in this sector.

Methods

The purpose of this systematic review was to investigate the occupational hazards faced by food delivery workers. The research question addressed in this study was: What occupational risks do food delivery workers experience?

A Systematic Literature Review was conducted using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) method, through searches in the databases of the U.S. National Library of Medicine of the National Institutes of Health (PubMed –U.S. National Library of Medicine, National Institutes of Health) and Scopus Library.[8]

The search was conducted from June 2025 to July 2025.

Through a systematic review, researchers aim to identify, evaluate, and synthesize all empirical data that meet specific predefined criteria. The goal is to answer a clearly defined research question with the highest possible level of reliability.

Clear inclusion and exclusion criteria were established prior to the literature search to ensure the selection of the studies relevant to the objectives of this systematic review. Studies were included if they met the following criteria: cross-sectional design, publication in English, inclusion of adult participants, and exclusive focus on food delivery workers.

Studies were excluded if they had any of the following criteria: systematic reviews and meta-analyses, studies published in languages other than English, studies included participants under 18 years old, or studies concerning workers involved in the delivery of products other than food.

For the conduct of the systematic review, the following keywords and phrases were used: work, occupation, job, accidents, hazards, safety, food delivery, delivery rider, food carrier.

To ensure an effective search and retrieval of all relevant studies, all possible combinations of these keywords were applied using Boolean operators in the PubMed database as follows:

(work [Title/Abstract] OR occupation [Title/Abstract] OR job [Title/Abstract]) AND (accidents [Title/Abstract] OR hazards [Title/Abstract] OR safety [Title/Abstract]) AND ("food delivery"[Title/Abstract] OR "delivery rider"[Title/Abstract] OR "food carrier"[Title/Abstract]).

The same search string was also used in the Scopus database with the necessary changes.

The methodological quality of the included studies was assessed using the Joanna Briggs Institute (JBI) Critical Appraisal Checklist for Prevalence Studies, which consists of nine items evaluating sample frame appropriateness, sampling methods, sample size adequacy, description of study subjects and setting, coverage of data analysis, validity and reliability of measurement tools, appropriateness of statistical analysis, and response rate management.[8]

Each item was rated as “Yes”, “No”, “Unclear”, or “Not applicable”.

For descriptive purposes, a modified quantitative approach was used, assigning 1 point for each “Yes” response (range: 0–9). Based on the total score, studies were categorized as having low (7–9), moderate (4–6), or high (0–3) risk of bias.

Results

From the systematic literature review, a total of 20 studies were identified that met all the inclusion criteria we had set. All other studies were excluded either because their subject matter was not relevant to the review's focus or because they did not meet the inclusion criteria. Figure 1 presents the stages of the systematic review process,[8] and Table 1 summarizes the findings of the articles included in the systematic review.

The methodological quality of the included studies was assessed using the Joanna Briggs Institute (JBI) Critical Appraisal Checklist for Prevalence Studies.[9]

Based on the JBI appraisal, a number of studies were classified as low risk of bias,[10-13], particularly those using validated measurement instruments, adequate sample sizes, and robust statistical analyses.

Most studies were classified as having moderate risk of bias,[14-26] primarily due to non-probability sampling and reliance on self-reported outcomes.

A small number of studies exhibited high risk of bias,[27-29] mainly owing to insufficient methodological detail and lack of validated measurement tools.

In table 1 are presented the quality assessment results.

The review of studies on food delivery workers highlights a range of complex occupational hazards, which can be classified into traffic-related, ergonomic, psychosocial, and socioeconomic risks.

1. Traffic Accidents and Risky Driving Behaviors:

Evidence from the reviewed studies indicates that risky driving behaviors are highly prevalent among food delivery workers. Commonly reported behaviors include running red lights, speeding, driving against traffic, using mobile phones while driving, and failing to wear protective helmets.[2,11,14,17,18,21,25–27,30] Reported accident involvement rates range from 25% to 70%, with severity influenced by factors such as age, experience, and employment duration. Specifically, younger age, limited work experience (<2 years), and lower educational attainment are correlated with a higher risk of accidents.[13,21] Furthermore, extended working hours (>8–10 hours per day) and high delivery volumes substantially increase the likelihood of accidents.[13,18,24] Time pressure and heavy workloads often compel couriers to adopt unsafe driving practices.[25-27] Some studies also report increased accident frequency during the afternoon and on midweek.[25] Finally, riders using two-wheeled vehicles face a greater risk of injury and assault compared to those driving cars.[10.31]

2. Ergonomic and Musculoskeletal Risks

Food delivery work involves prolonged sitting, exposure to vibrations, and repetitive movements. Most studies report a high prevalence of musculoskeletal disorders, with symptoms most frequently affecting the lumbar spine, back, neck, and shoulders.[10,16,19,23,30] Over 70% of participants in relevant studies reported experiencing lower back or back pain within the past year.[16,32] Exposure to whole-body vibration (WBV) has been identified as a major risk factor, particularly among riders using sedan-type motorcycles.[30,32] Contributing factors to the development of musculoskeletal problems include extended working hours, lack of ergonomic equipment, fatigue, and improper body posture while riding.[10,16,32] Exposure to vibration levels exceeding recommended limits has been linked to a twofold increase in the likelihood of developing low back pain, while long working hours and consecutive workdays exacerbate these symptoms.[19,30]

3. Psychosocial and Organizational

Delivery workers frequently experience elevated levels of occupational stress, exhaustion, and emotional fatigue because of demanding

working conditions.[19,24,32] Evidence suggests that couriers reporting high stress levels are up to six times more likely to be involved in an accident compared to those experiencing mild stress.[12,24] Moreover, occupational burnout and excessive job demands are associated with decreased attention and increased unsafe work behaviors.[12] Factors such as time pressure, income uncertainty, and job insecurity further intensify stress and fatigue, often accompanied by physical symptoms including headaches, insomnia, and a general sense of discomfort.[19,27]

4. Socioeconomic Factors

Several studies have demonstrated an association between socioeconomic status and occupational safety among delivery workers. Injury rates are higher among individuals who rely solely on their courier income, as financial dependence often leads them to disregard safety regulations to maintain earnings.[26,28] Furthermore, the phenomenon of presenteeism (continuing to work despite illness) has been reported in approximately 27% of cases.[19] In terms of demographic characteristics, most couriers are male, young, and have low levels of education. These factors have been linked to increased occupational risk and reduced access to preventive measures and training opportunities.[2,11,14,25,30]

In Table 2 are summarized some of the characteristics of the studies.

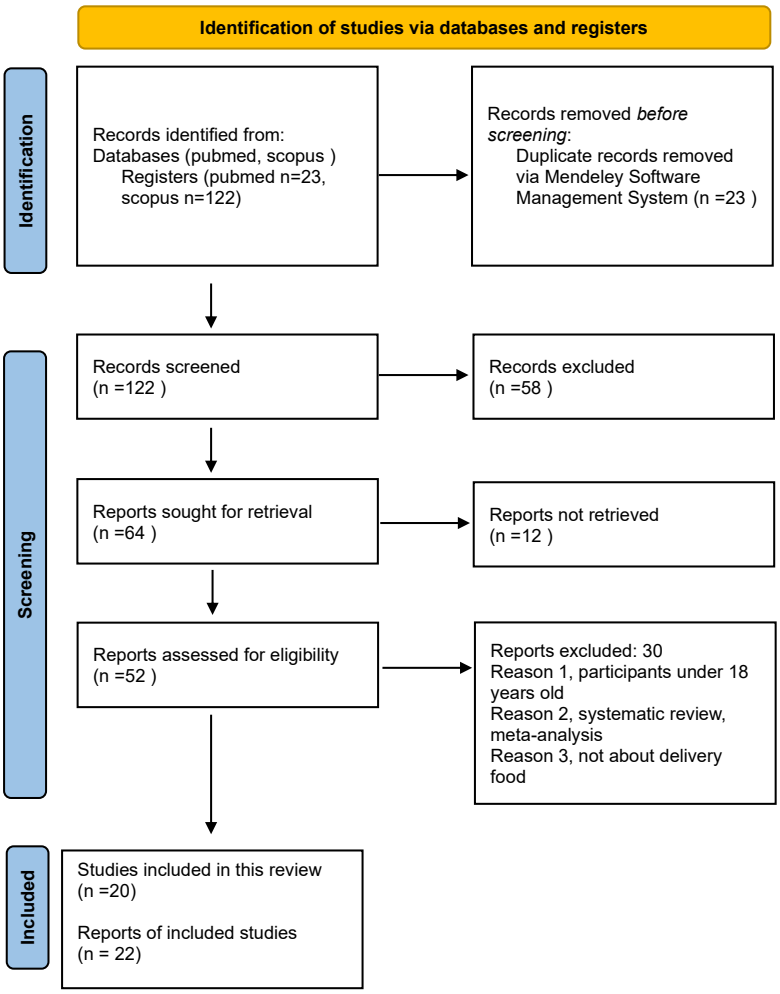


Figure 1: PRISMA 2020 Flow Diagram, Phases of the Systematic Review Process

Table 1: JBI Critical Appraisal Checklist for Prevalence Studies

Study	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Total score	Risk of Bias
China, Zheng Y et al, 2019	yes	no	yes	yes	yes	unclear	unclear	yes	unclear	5	moderate
France, Aguilera et al, 2022	yes	no	yes	yes	yes	unclear	unclear	yes	unclear	5	moderate
Vietnam, Duy Quy et al, 2023	yes	unclear	yes	yes	yes	unclear	unclear	yes	unclear	5	moderate
Australia, Jolene AC et al, 2023	unclear	no	no	yes	yes	unclear	unclear	yes	unclear	3	high
Thailand, Champahom T et al, 2025	yes	unclear	unclear	unclear	yes	yes	unclear	yes	unclear	4	moderate
India, Thomas M Benson et al, 2025	yes	unclear	unclear	yes	unclear	unclear	unclear	unclear	unclear	2	high
China, Zihao Zhang et al, 2023	yes	no	unclear	yes	yes	yes	yes	unclear	unclear	5	moderate
Vietnam, Nhat Xuan Mai et al, 2025	yes	no	yes	yes	yes	unclear	unclear	yes	unclear	5	moderate
Malaysia, Rishikesavan Ragupathy et al, 2024	yes	no	yes	yes	yes	unclear	unclear	yes	Unclear	5	moderate
Brazil, Marcelo Werneck Barbosa et al, 2025	yes	unclear	yes	yes	yes	unclear	unclear	yes	unclear	5	moderate
Romania, Man TC et al, 2024	yes	unclear	unclear	yes	yes	yes	unclear	unclear	unclear	4	moderate
China, Wanwaen C et al, 2024	yes	unclear	unclear	yes	unclear	unclear	unclear	unclear	unclear	2	high
Thailand, Molo M et al, 2024	yes	no	yes	yes	yes	unclear	unclear	yes	yes	6	moderate
Malaysia, Daud A et al, 2025	yes	no	yes	yes	yes	yes	yes	yes	yes	7	low
USA, Laskaris Z et al, 2025	yes	yes	yes	yes	yes	yes	unclear	yes	yes	7	low
Korea, Hyoungseob Yoo et al, 2024	yes	unclear	yes	yes	yes	no	unclear	yes	unclear	5	moderate
Thailand, Kwangsukstith S et al, 2025	yes	unclear	yes	yes	yes	unclear	unclear	yes	unclear	5	moderate
Italy, Boniardi L et al, 2024	yes	yes	yes	yes	yes	yes	yes	yes	unclear	8	low
Greece, Papakostopoulos V et al, 2021	yes	no	unclear	yes	yes	unclear	unclear	yes	unclear	4	Moderate

Table 2: Studies Identified Through the Systematic Review

Country/ Researchers/ Year	Population	Age	Educational Level	Years of Experience as Food Delivery Workers	Working hours/ day	Working days/ week
China, Zheng Y et al, 2019	824	8.4% 18-25 y , 33.5% 26-30 y, 38.9% 31-35 y, 14.8% 36-40 y , 4.4% 41-50 y	7.8% primary school, 53.2% junior high school, 30.5% senior high school, 8.5% college	39.8% 1-2 years , 27.6% 2-3 years, 25.2% 3-4 years, 7.4% >4 years	7.1% <7 h, 18.7% 7-8 h, 37.1% 8-9 h , 30.8% 9-10 h, 5.8% 10-11 h, 0.5% >11 h	
France, Aguilera A et al, 2022	517 (2021), 300 (2020)	66% <25 y (2021), 88% <25 y (2020)	38 % no diploma (2021), 40% no diploma (2020)	67% <1y (2021), 79%, <1y (2020)		28% 5 days, 40% 6 days, 17% 7 days
Vietnam, Duy Quy Nguyen-Phuoc et al, 2023	554	Mean (SD) 25.66 y (5.54)	96 (17.3%) high school, 205 (37%) college, 182 (32.9%) university, 31 (5.6%) above university, 40 (7.2%) other			
Australia , Jolene A. Cox et al, 2023	71 gig workers (ride-hailing , courier , and food delivery services via digital platforms)	Mean (SD) 33.54 y (9.30)		Mean (SD) 20.71 (15.68) <5 years	Mean (SD) 22.14 (13.90) 4-70 h/ week	
Thailand, Thanapong Champahom et al, 2025	2000	73.5% 25-44 y	83.5% high school or higher education	86% >5 years	56.7% 9-12 hours	45.4% 7 days

India, Thomas M. Benson et al, 2025	425	128 (30.1%) <25 y, 107 (25.2%) 26-29 y, 101 (23.8%) 30-34 y, 89 (20.9%) >35 y	58 (13,7%) secondary school or below, 129 (30,4%) diplomas, 238 (56%) Graduate or postgraduate	128 (30.1%) <1year, 129 (30.4%) 1-2 y, 168 (39.5%) >2 y		
China, Zihao Zhang et al, 2023	46	26 (56.5%) 26-35 y, 5 (10.9%) 36-45 y, 2 (4.3%) >45 y	21 (45.7%) high school, 12 (26.1%) junior college, 2 (4.3%) bachelor's degree or above, 6 (13%) higher education	10 (21.7%) <6, 7 (15.2%) 6-12 m, 20 (43.5%) 1-3 years, 9 (19.6%) >3 y	33 (71.7%) 8-12 hours, 8 (17.4%) >12 h	
China, Zhan Jing et al, 2023	5703	Mean 33.906				
Vietnam, Nhat Xuan Mai et al, 2025	419		45.8% high school, 21% college, 25.1% university, 0.7% above university, 7.4% other			
Malaysia, Rishikesavan Ragupathy et al, 2024	207	45 (21.7%) 18-23 y, 98 (47.3%) 24-29 y, 64 (30.9%) 30-35 y	143 (69.1%) secondary school, 64 (30.9%) university or college	74 (35.7%) 7 months – 1 year, 126 (60.9%) 2-5 y, 7 (3.4%) 6-10 y	81 (39.1%) 7-9 hours, 126 (60.9%) >10 h	2 (1%) <2 days, 9 (4.3%) 3-4 days, 74 (35.7%) 5-6 days, 122 (58.9%) 7 days
Brazil, Marcelo Werneck Barbosa et al, 2025	295	Average age 30 years	53.6% high school, 90.2% elementary school			
Romania, Titus Cristian et al, 2024	168					
China, Wanwaen C et al, 2024	253	134 (53%) <30 y, 119 (47%) >30 y	126 (49.8%) primary/ secondary school, 57 (22.5%) undergraduate, 70 (27.7%) graduate or higher	41 (16.2%) 1-5 years, 105 (41.5%) 6-10 y, 41 (16.2%) 11-15 y, 66 (26.1) >15 y	101 (39.9%) <8 hours, 152 (60.1%) >8 hours	

Thailand, Molo M et al, 2024	257	109 <30 y, 120 30-45 y, 26 46-60 y, 2 >60 y	7 primary school, 104 secondary school, 146 higher education	93 <12 months, 74 13-35 m, 90 >36 m	103 <8 h, 154 >8 h	
Malaysia, Daud A. et al, 2025	191	Mean (SD) 27.6 y (5.76)	5 (2.6%) non formal, 4 (2.1%) primary school, 84 (44%) secondary school, 76 (39.8%) diploma, 22 (11.5%) degree/ master/ PHD	92 (48.2%) 6-12 months, 99 (51.8%) >12 m	10.2 +/- 2.33 h/ day	6.1 +/- 1.03 days/ week
USA, Laskaris Z et al, 2025	1650	248 (15%) 18-24 y, 665 (40.3%) 25-34 y, 470 (28.5%) 35-44 y, 267 (16.2%) >45 y		314 (19%) <1y, 411 (24.9%) 1-2 y, 381 (23.1%) 2-3 y, 168 (10.25) 3-4 y, 376 (22.8%) >4 y	617 (37.4%) <20 hours, 568 (34.4%) 20-39 h, 465 (28.2%) >40 h	
Korea, Hyoungseob Yoo et al, 2024	400	6 (1.5%) 18-20 y, 76 (19%) 20-30 y, 171 (42.8%) 30-40 y, 82 (20.5%) 40-50 y, 53 (13.2%) 50-60 y, 12 (3%) >60 y	263 (65.8%) high school or lower, 114 (28.5%) 2year college, 23 (5.7%) University or higher	3.08 +/- 1.9 years	7.38 +/- 1.9 hours / day	5.70 +/- 0.8 Days / week
Thailand, Kwangsukstith, S. Et al, 2025	709	36 (5.1%) <20 y, 403 (56.8%) 21-35 y, 218 (30.7%) 36-45 y, 52 (7.3%) >46 y	35 (4.9%) primary school, 325 (45.8%) secondary school, 110 (15.5%), Diploma 239 (33.7%) Bachelor or higher	Mean 2 years	Mean 54 Hours/ week	
Italy, Boniardi L et al, 2024	240	47 (20%) <25 y, 69 (29%) 25-29 y, 46 (19%) 30-34 y, 69 (29%) >35 y	28 (12%) Degree/ master or higher, 97 (40%) High school, 102 (43%) middle school or primary school, 3 (1%) other	47 (20%) <12 m, 151 (63%) 12-36 m, 37 (15%) >3 6 m	10 (4%) <3 h, 47 (20%) 3-4 h, 60 (25%) 5-6 h, 61 (25%) 7-8 h, 56 (23%) >8 h	8 (3%) <3 days, 32 (13%) 3-4 days, 90 (38%) 5-6 days, 105 (44%) 7 days

Thailand, Siriaran Kwangsukkstith et al, 2024	709	36 (5.1%) <20 y, 403 (56.8%) 21-35 y, 218 (30.7%) 36-45 y, 52 (7.3%) >46 y	35 (4.9%) primary school, 325 (45.8%) secondary school, 110 (15.5%) diplomas, 239 (33.7%) bachelor or higher	483 (68.1%) >1 year	547 (77.2%) >8 h/day, 503 (70.9%) >48 h/ week	
Greece, Vassilis Papakostopoulos et al, 2021	434	63.1% >25 y		78.8% >5 years		

Discussion

The present systematic review highlighted the significant occupational risks faced by food delivery workers. This profession is among the most hazardous in the modern labor market, as the nature of the work exposes employees to multiple hazards daily.

Work-related musculoskeletal disorders (WMSDs) represent the most common occupational illness in various countries, including Japan, the United States, and the Scandinavian countries.[29,33] The primary contributing factors are prolonged static postures, non-ergonomic working positions, and extended exposure to vibrations.[33,34] Similarly, the studies reviewed indicate that food delivery workers frequently experience musculoskeletal disorders due to the nature of their work. Low back pain is the most reported symptom, followed by discomfort in other body regions such as the neck, back, shoulders, thighs, and knees.

Occupational accidents are also relatively common among food delivery workers, primarily due to time pressure and demanding working conditions that encourage risky behaviors. The most frequently reported dangerous driving behaviors include riding in the wrong lane, running red lights, exceeding speed limits, and using mobile phones while driving. Most studies associated these behaviors with younger age and limited work experience. Additionally, long working hours, fatigue, adverse weather conditions (e.g., rain), and a high proportion of temporary or new workers were associated with higher accident rates. Tight delivery deadlines, extended working hours, and the unpredictability of orders contribute to stress, fatigue, and reduced concentration, further increasing the risk of accidents.

In terms of injuries resulting from traffic accidents, abrasions, strains, contusions, and fractures of the upper and lower extremities were reported.

Moreover, the studies also highlighted exposure to psychosocial risk factors, including verbal and physical violence, threats, and harassment. Delivery workers often face rude customers, heavy workloads, and job instability, which can lead to stress, insecurity, and psychological fatigue.

Finally, in many cases, work is performed without adequate insurance coverage or proper personal protective equipment, such as helmets, gloves, reflective gear, or clear safety instructions from employers.

A similar review by Useche and colleagues indicates that rates of road traffic accidents are particularly high among delivery workers (57). At the same time, musculoskeletal disorders—manifesting as pain in the neck, shoulders, lower back, and knees—are a common problem, resulting from prolonged sitting, driving-related vibrations, and carrying loads in unbalanced postures.[36]

Furthermore, other reviews highlight the psychological pressure and stress couriers experience due to job insecurity and income uncertainty.[5,35,37] This occupation also involves exposure to violence or harassment from customers or other drivers on the road, further compromising mental health.[35]

Finally, exposure to environmental hazards, such as vehicle exhaust, solar radiation, high temperatures, and air pollution, worsens working conditions and increases the risk of respiratory and dermatological problems.[5]

The findings of the present review are consistent with those reported in previous studies, which report similar occupational risks for food delivery workers.

This systematic review has several limitations that should be acknowledged. First, the available literature is limited and heterogeneous in study populations, making comparison and generalization of findings challenging. Additionally, due to publication bias, studies reporting positive or statistically significant results are more likely to be published, potentially affecting the comprehensiveness of the review. Finally, the search was restricted to two databases and to studies published in English, which may have resulted in the exclusion of relevant studies.

This systematic review on the occupational risks faced by delivery workers can serve as a reference point for the development of preventive and intervention strategies, as well as for the design of public health policies aimed at improving working conditions for couriers. Identifying the causes of traffic accidents can provide a basis for the implementation of mandatory road safety training programs. Similarly, documenting musculoskeletal burdens may inform regulations that limit consecutive working hours and mandate the use of personal protective equipment, such as high-quality helmets or reflective vests. Systematic recording of the effects of exposure to extreme weather conditions could support the need for mandatory work breaks during heatwaves or extreme cold, as well as the provision of specialized equipment (e.g., insulated clothing, waterproof suits).

At the psychosocial level, the review highlights the need for measures to address job insecurity and stress stemming from the instability of platform-based work. This could be integrated into worker protection policies through more stable employment contracts or by providing rights such as insurance coverage and sick leave.

Furthermore, the work of delivery workers, under exhausting schedules and without adequate rest, increases the risk of traffic accidents for all road users. Therefore, establishing regulations limiting excessive work intensity could contribute to both reducing occupational risks and enhancing public safety.

Finally, this review provides practical tools and evidence-based guidance to occupational health practitioners in order to make targeted interventions.

Conclusion

In summary, the reviewed studies indicate that food delivery workers face multidimensional occupational risks that affect not only their road safety but also their physical and mental health. Time pressure, prolonged working hours, unsafe driving practices, and inadequate health protection contribute to a higher incidence of accidents, musculoskeletal disorders, and psychological strain.

The findings underscore the need for comprehensive preventive interventions that combine road safety training, ergonomic measures, psychosocial support, and improvements in working conditions. Adherence to traffic safety regulations, the use of appropriate personal protective equipment, proper shift organization, and provision of insurance coverage are essential prerequisites for reducing risks and safeguarding the health of delivery workers.

References

1. Wang C, Chen J, Xie P. Observation or interaction? Impact mechanisms of gig platform monitoring on gig workers' cognitive work engagement. Int J Inf Manage. Dec 2022;67:102548. Available from: https://doi.org/10.1016/j.ijinfomgt.2022.102548

2. Zheng Y, Ma Y, Guo L, Cheng J, Zhang Y. Crash Involvement and Risky Riding Behaviors among Delivery Riders in China: The Role of Working Conditions. Transportation Research Record: Journal of the Transportation Research Board. Apr 7;2673(4):1011–22. Available from: https://doi.org/10.1177/0361198119841028

3. Yd J, Lestari F, Tejamaya M, Prasetyo S, Fikawati S, Ih N, et al. Occupational safety and health education for reducing workplace accidents in oil palm plantations. Int J Occup Safety Health. 2025;15(4):361–9. Available from: https://doi.org/10.3126/ijosh.v15i4.76198

4. Azizah U, Indrayani R, Hartanti RI. Determinan of Safety Riding on Gojek Rider Community at the Jember Regency. The Indonesian Journal of Occupational Safety and Health. 2024 Aug 31;13(2):229–40. Available from: https://doi.org/10.20473/ijosh.v13i2.2024.229-240

5. Margerison CE, Joachim GE, Michling TR, Johnson CY. Platform-Mediated Gig Work and Health: A Scoping Review. Am J Ind Med. 2025 Sep 15;68(9):729–39. Available from: https://doi.org/10.1002/ajim.70007

6. Shashidhar ES, Kumar VH, Srikanth K. A Study on the types of abuses faced by food delivery workers and its impact on them in Bangalore. 2024;12(1):2319-29. Available from: https://ijip.in/articles/food-delivery-workers/

7. Gnana Chellaiyan VD, Kumar AR, Jeyapaul Rajan TE. Assessment of work-life balance among married female healthcare workers in a tertiary care hospital of Chengalpattu district, Tamil Nadu: A cross-sectional study. Int J Occup Safety Health. 2024;14(3):319–26. Available from: https://doi.org/10.3126/ijosh.v14i3.60757

8. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ. 2021;372:n71. Available from: https://doi.org/10.1136/bmj.n71

9. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med. 2009 Jul 21;6(7):e1000097. Available from: https://doi.org/10.1371/journal.pmed.1000097

10. Boniardi L, Campo L, Prudenzi S, Fasano L, Natale P, Consonni D, et al. Occupational Safety and Health of Riders Working for Digital Food Delivery Platforms in the City of Milan, Italy. Med Lav. 2024 Oct 24;115(5):e2024035. Available from: https://doi.org/10.23749/mdl.v115i5.16278

11. Aguilera A, Dablanc L, Krier C, Louvet N. Platform-based food delivery in Paris before and during the pandemic: profile, motivations and mobility patterns of couriers. European Transport Research Review. 2022 Dec 5;14(1):45. Available from: https://doi.org/10.1186/s12544-022-00569-8

12. Quy Nguyen-Phuoc D, Ngoc Thi Nguyen L, Ngoc Su D, Nguyen MH, Oviedo-Trespalacios O. Deadly meals: The influence of personal and job factors on burnout and risky riding behaviours of food delivery motorcyclists. Saf Sci. 2023 Mar;159:106007. Available from: https://doi.org/10.1016/j.ssci.2022.106007

13. Champahom T, Se C, Laphrom W, Jomnonkwao S, Kasemsri R, Ratanavaraha V. Determinants of crash injury severity for delivery riders: Insights from an error components mixed logit model with heterogeneous means and variances. IATSS Research. 2025 Jul;49(2):180–90. Available from: https://doi.org/10.1016/j.iatssr.2025.04.001

14. Zhang Z, Liu C. Exploration of Riding Behaviors of Food Delivery Riders: A Naturalistic Cycling Study in Changsha, China. Sustainability. 2023 Nov 23;15(23):16227. Available from: https://doi.org/10.3390/su152316227?urlappend=%3Futm_source%3Dresearchgate.net%26utm_medium%3Darticle

15. Pervez A, Nguyen-Phuoc DQ, Mai NX, Vo DQN, Lee JJ. Understanding motorcycle crash involvement: Insights from regular motorcyclists and food delivery

riders in Vietnam. Accid Anal Prev. 2025;216:108024. Available from: https://doi.org/10.1016/j.aap.2025.108024

16. Ragupathy R, Ooi M, Wah YC, Chinnavan E. Prevalence and the Associated Risk Factors of Low Back Pain among Commercial Motorcycle Riders in Kedah, Malaysia: A Cross-Sectional Study. Univers J Public Health. 2024;12(6):1029–41. Available from: https://doi.org/10.13189/ujph.2024.120601

17. Man TC, Andor CF. "Urban Mobility and Safety: Traffic Risks for Migrant Food Delivery Workers in Romania. Case Study: Cluj-Napoca Municipality". Journal of Settlements and Spatial Planning. 2024;15(1):57–65. Available from: https://doi.org/10.24193/JSSP.2024.1.05

18. Molo M, Changsan S, Madares L, Changkwanyeun R, Wattanasoei S, Vittaporn S, et al. A decision tree model for traffic accident prediction among food delivery riders in Thailand. Epidemiol Health. 2024;46:e2024095. Available from: https://doi.org/10.4178/epih.e2024095

19. Yoo H, Yang M, Song JH, Yoon JH, Lee W, Jang J, et al. Investigation of Working Conditions and Health Status in Platform Workers in the Republic of Korea. Saf Health Work. 2024;15(1):17–23. Available from: https://doi.org/10.1016/j.shaw.2024.01.002

20. Kwangsukstith S, Surawattanasakul V, Mahakkanukrauh C, Panumasvivat J, Sirikul W. Assessment of occupational hazards, health effects, and personal protective equipment usage among motorcycle food delivery riders in Thailand: a cross-sectional survey. Journal of Occupational Medicine and Toxicology. 2025 May 10;20(1):13. Available from: https://doi.org/10.1186/s12995-025-00460-x

21. Papakostopoulos V, Nathanael D. The Complex Interrelationship of Work-Related Factors Underlying Risky Driving Behavior of Food Delivery Riders in Athens, Greece. Saf Health Work. 2021 Jun;12(2):147–53. Available from: https://doi.org/10.1016/j.shaw.2020.10.006

22. Cox JA, Read GJM, Butler GL, Salmon PM. Examining gender differences in gig worker safety. Human Factors and Ergonomics in Manufacturing & Service Industries. 2024 Jan 4;34(1):3–15. Available from: https://doi.org/10.1002/hfm.21007

23. Benson TM, Sathiyarajeswaran NS, Radhakrishnan R, Gaffoor AA, Krupalakshme M, Samal J. Factors and prevalence of musculoskeletal pain among the App-based food delivery riders in Tamil Nadu: a cross-sectional study. Discover Social Science and Health. 2025 Feb 10;5(1):14. Available from: https://doi.org/10.1007/s44155-025-00162-z?urlappend=%3Futm_source%3Dresearchgate.net%26utm_medium%3Darticle

24. Wanwaen C, Ong-artborirak P, Chautrakarn S. Stress and work-related accidents among food delivery riders in Chiang Mai, Thailand. J Health Res. 2024 Sep 2;38(5). Available from: https://doi.org/10.56808/2586-940X.1095

25. Mai NX, Nguyen-Phuoc DQ, Nguyen B Van, Pervez A, Oviedo-Trespalacios O. Traffic crash risk among on-demand food delivery riders in Danang city, Vietnam: Key contributing factors. Travel Behav Soc. 2025 Jul;40:100995. Available from: https://doi.org/10.1016/j.tbs.2025.100995

26. Barbosa MW, de Oliveira Miranda JV, de Oliveira LK. Identification of antecedents of risky driving behavior of food delivery riders: An analysis during the COVID −19 pandemic in Brazil. Case Stud Transp Policy. 2025 Jun;20:101403. Available from: https://doi.org/10.1016/j.cstp.2025.101403

27. Kwangsukstith S, Surawattanasakul V, Mahakkanukrauh C, Panumasvivat J, Sirikul W, Kitro A, et al. Major injuries and associated factors in traffic accidents among motorcycle food delivery riders during the COVID-19 pandemic in Thailand. Heliyon. 2024 Oct;10(20):e39032. Available from: https://doi.org/10.1016/j.heliyon.2024.e39032

28. Jing Z, Yuru L, Yue Z. More reliance, more injuries: Income dependence, workload and work injury of online food-delivery platform riders. Saf Sci. 2023 Nov;167:106264. Available from: https://doi.org/10.1016/j.ssci.2023.106264

29. Gasibat Q, Bin Simbak N, Abd Aziz A. Stretching Exercises to Prevent Work-related Musculoskeletal Disorders – A Review Article. American Journal of

Sports Science and Medicine. 2017 Aug 26;5(2):27–37. Available from: https://doi.org/10.12691/ajssm-5-2-3

30. Daud A, Mohd Basri IS, Ahmad E, Hairon SM, Azmir NA, Md Jalil AS, et al. Determinants of Work-Related Musculoskeletal Disorders Among Food Delivery Riders in Eastern Peninsular Malaysia: An Ergonomic Risk Assessment. Healthcare. 2025;13(6):645. Available from: https://doi.org/10.3390/healthcare13060645

31. Laskaris Z, Hussein M, Stimpson JP, Vignola EF, Shahn Z, Cohen N, et al. A Price Too High: Injury and Assault among Delivery Gig Workers in New York City. Journal of Urban Health. 2024 Jun 29;101(3):439–50. Available from: https://doi.org/10.1007/s11524-024-00873-9

32. Daud A, Mohd Basri IS, Ahmad E, Mohd Hairon S, Nordin R, Azmir NA, et al. Assessing ergonomic risks: REBA analysis of food delivery riders in Eastern Peninsular Malaysia. Int J Occup Med Environ Health. 2025;38(2):170–8. Available from: https://doi.org/10.13075/ijomeh.1896.02558

33. Punett L WD. Work-related musculoskeletal disorders: The epidemiologic evidence and the debate. . Journal of Electromyography and Kinesiology. 2004 Sep 15;14(1):13–23. Available from: https://doi.org/10.1016/j.jelekin.2003.09.015

34. Vitharana VHP, Chinda T. Structural equation modelling of lower back pain due to whole-body vibration exposure in the construction industry. International Journal of Occupational Safety and Ergonomics. 2019 Apr 3;25(2):257–67. Available from: https://doi.org/10.1080/10803548.2017.1366119

35. Useche SA, Traficante S, Llamazares FJ, Marin C. The human cost of fast deliveries: A systematic literature review of occupational risks and safety outcomes in last-mile delivery workers. J Transp Health. 2025 Oct;44:102133. Available from: https://doi.org/10.1016/j.jth.2025.102133

36. Useche SA, Robayo S, Orozco-Fontalvo M. The hidden cost of your 'too fast food': stress-related factors and fatigue predict food delivery riders' occupational crashes. International Journal of Occupational Safety and Ergonomics. 2024 Sep;30(3):825-34. Available from: https://doi.org/10.1080/10803548.2024.2356997

37. Agyemang CB, Darkwah E, Acquah-Coleman R, Hansen-Garshong R, Nkansah EA, Hagan S, et al. Occupational health outcomes of work in the gig economy: a systematic review protocol. BMJ Open. 2025 Sep 21;15(9):e103005. Available from: https://doi.org/10.1136/bmjopen-2025-103005

International Journal of Occupational Safety and Health

ISSN: 2091-0878 (Online) ISSN: 2738-9707 (Print)

Review Article

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

Otitolaiye VO†[1], Omer F†[1], Mahfud R[1], Abdelrahim R[1], Kozhiparambath L[1], Elbadri H[1], Al-Bahri A[1]

[1]Department of Health, Safety and Environmental Management, International College of Engineering and Management, Oman.
† These authors contributed equally to this work and share first authorship.

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

Date of submission: 20.01.2026
Date of acceptance: 30.03.2026
Date of publication: 15.04.2026

Conflicts of interest: None
Supporting agencies: None
DOI:
https://doi.org/10.3126/ijosh.v16i1.89847

Copyright: This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License

ABSTRACT

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 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.

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 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.

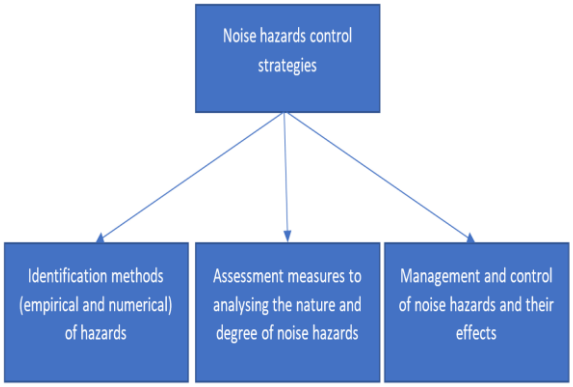


Figure 1: Classification of strategies for noise hazards control and management.

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
Yaoyueyong 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,

Nanthavanij [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/s^2 and 0.5 m/s^2, and limit values of 5.0 m/s^2 and 1.15 m/s^2, 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 hazards [47], 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.

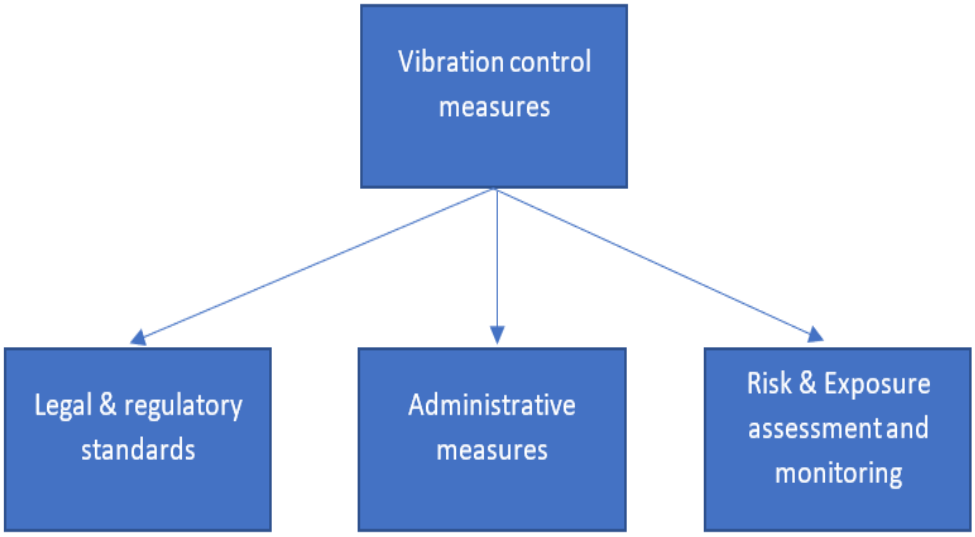


Figure 2: Classification of strategies for noise hazards control and management in the workplace.

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.

Acknowledgement

The authors would like to acknowledge all those who indirectly contributed to the development of this review.

References

1. Thaper R, Sesek R, Garnett R, Acosta-Sojo Y, Purdy GT. The combined impact of hand-arm vibration and noise exposure on hearing sensitivity of agricultural/forestry workers—a systematic literature review. Int J Environ Res Public Health. 2023;20(5):4276. Available from: https://doi.org/10.3390/ijerph20054276
2. Franz RM, Phillips JI. Noise and vibration. Handbook of Occupational Health Practice in the South African Mining Industry. Safety in Mines Research Advisory Committee (SIMRAC); 2001:193–230. Available from: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://elibrary.mhsc.org.za/uploads/events/docs/custom_1768977382_39f158dc.pdf
3. Chen X, Liu M, Zuo L, Wu X, Chen M, Li X, et al. Environmental noise exposure and health outcomes: an umbrella review of systematic reviews and meta-analysis. European Journal of Public Health. 2023;33(4):725–31. Available from: https://doi.org/10.1093/eurpub/ckad044
4. Themann CL, Masterson EA. Occupational noise exposure: A review of its effects, epidemiology, and impact with recommendations for reducing its burden. The Journal of the acoustical society of America. 2019;146(5):3879–905. Available from: https://doi.org/10.1121/1.5134465
5. Leensen M, Van Duivenbooden J, Dreschler WA. A retrospective analysis of noise-induced hearing loss in the Dutch construction industry. International archives of occupational and environmental health. 2011;84(5):577–90. Available from: https://doi.org/10.1007/s00420-010-0606-3
6. Samara P, Athanasopoulos M, Markatos N, Athanasopoulos I. From sound waves to molecular and cellular mechanisms: Understanding noise induced hearing loss and pioneering preventive approaches (Review). Medicine International. 2024;4(6):60. Available from: https://doi.org/10.3892/mi.2024.184
7. Babisch W. Stress hormones in the research on cardiovascular effects of noise. Noise and Health. 2003;5(18):1–11. Available from: https: https://pubmed.ncbi.nlm.nih.gov/12631430/
8. Bovenzi M. Exposure-response relationship in the hand-arm vibration syndrome: an overview of current epidemiology research. International Archives of Occupational and Environmental Health. 1998;71(8):509–19. Available from: https://doi.org/10.1007/s004200050316
9. Griffin MJ. A comparison of standardized methods for predicting the hazards of whole-body vibration and repeated shocks. J Sound Vib. 1998;215(4):883–914. Available from: https://doi.org/10.1006/jsvi.1998.1600
10. Krajnak K. Health effects associated with occupational exposure to hand-arm or whole body vibration. Journal of Toxicology and Environmental Health, Part B. 2018;21(5):320–34. Available from: https://doi.org/10.1080/10937404.2018.1557576
11. Cudjoe FA, Opoku DA, Ayisi-Boateng NK, et al. Health effects of occupational noise exposure on heavy-duty equipment operators and exposed workers in a mining firm in Ghana. PLoS One. 2025;20(9):e0332600. Availablefrom: https://doi.org/10.1371/journal.pone.0332600
12. International Organization for S. ISO 5349-1:2001 Mechanical vibration – Measurement and evaluation of human exposure to hand-transmitted vibration – Part 1: General requirements. 2001:62. Available from:

https://www.iso.org/obp/ui/#iso:std:iso:5349:-1:ed-1:v1:en

13. International Organization for S. ISO 2631-1:1997 Mechanical vibration and shock – Evaluation of human exposure to whole-body vibration – Part 1: General requirements. 1997. Available from: https://www.iso.org/obp/ui/es/#iso:std:iso:2631:-1:ed-2:v2:en
14. European P, Council. Directive 2003/10/EC of 6 February 2003 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (noise). Vol. L42. 2003:38–44. Available from: https://osha.europa.eu/en/legislation/directives/82#:~:text=Directive%202003/10/EC%20of,85%20decibels%20(upper%20value)
15. European P, Council. Directive 2002/44/EC of 25 June 2002 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibration). Vol. L177. 2002:13–19. Available from: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://eur-lex.europa.eu/resource.html?uri=cellar:546a09c0-3ad1-4c07-bcd5-9c3dae6b1668.0004.02/DOC_1&format=PDF#:~:text=As%20a%20first%20step%2C%20it,avoid%20possible%20distortions%20of%20competition
16. Weier MH. The association between occupational exposure to hand–arm vibration and hearing loss: a systematic literature review. Saf Health Work. 2020;11(3):249–61. Availablefrom: https://doi.org/doi:10.1016/j.shaw.2020.04.003
17. Golmohammadi R, Darvishi E. The combined effects of occupational exposure to noise and other risk factors − a systematic review. Noise and Health. 2019;21(101):125–141. Available from: https://journals.lww.com/nohe/fulltext/2019/21010/the_combined_effects_of_occupational_exposure_to.1.aspx
18. Tikka C, Verbeek JH, Kateman E, Morata TC, Dreschler WA, Ferrite S. Interventions to prevent occupational noise-induced hearing loss. Cochrane Database of Systematic Reviews. 2017;(7):CD006396. Available from: https://doi.org/10.1002/14651858.cd006396.pub4
19. Baethge C, Goldbeck-Wood S, Mertens S. SANRA—a scale for the quality assessment of narrative review articles. Research Integrity and Peer Review. 2019;4(1):5. Available from: https://doi.org/10.1186/s41073-019-0064-8
20. Elert G. The nature of sound–the physics hypertextbook. physics info Retrieved. 2016:06–20.
21. EPD. What is Sound and What is Noise? Government of the Hong Kong Special Administrative Region. Available from: https://www.epd.gov.hk/epd/noise_education/web/ENG_EPD_HTML/m1/intro_1.html
22. Vašina M. Advanced Materials Structures for Sound and Vibration Damping. MDPI. 2022;15(4):1295. Available from: https://doi.org/10.3390/ma15041295
23. Bolaji BO, Olanipekun MU, Adekunle AA, Adeleke AE. An analysis of noise and its environmental burden on the example of Nigerian manufacturing companies. J Clean Prod. 2018;172:1800–6. Available from: https://doi.org/10.1016/j.jclepro.2017.12.007
24. WHO. Noise. World Health Organisation. Updated 2023. Available from. https://www.who.int/europe/news-room/fact-sheets/item/noise
25. Lai A-J, Huang C-Y. Effect of occupational exposure to noise on the health of factory workers. Procedia Manufacturing. 2019;39:942–6. Available from: https://doi.org/10.1016/j.promfg.2020.01.395
26. Haverkamp M. How does what we hear sound? The qualia problem in acoustics. 2019. Available from: https://www.researchgate.net/publication/335756926_How_does_what_we_hear_sound_The_qualia_problem_in_acoustics#:~:text=complete%20descr,consciousness
27. Cooper C. The Basics of Sound. Rosen Publishing. 2014. Available from: https://www.scribd.com/document/1018493095/Cooper-C-the-Basics-of-Sound-2014
28. Ball L, Ben D, Hilary L, et al. Super Simple Physics: The Ultimate Bitesize Study Guide. Dorling Kindersley Limited; 2021. Available from:

https://archive.org/details/super-simple-physics-the-ultimate-bitesize-study-guide-by-dk-z-lib.org_202109

29. Mayntz SP, Rosenbech KE, Mohamed RA, Lindholt JS, Diederichsen ACP, Frohn LM, et al. Impact of air pollution and noise exposure on cardiovascular disease incidence and mortality: A systematic review. Heliyon. 2024;10(21):e39844. Available from: https://doi.org/10.1016/j.heliyon.2024.e39844

30. Hahad O, Kuntic M, Al-Kindi S, Kuntic I, Gilan D, Petrowski K, et al. Noise and mental health: evidence, mechanisms, and consequences. Journal of Exposure Science & Environmental Epidemiology. 2024;35:16-23. Available from: https://doi.org/10.1038/s41370-024-00642-5

31. Mehrotra A, Shukla SP, Shukla AK, Manar MK, Singh SK, Mehrotra M. A comprehensive review of auditory and non-auditory effects of noise on human health. Noise and Health. 2024;26(121):59–69. Available from: https://doi.org/10.4103/nah.nah_124_23

32. Yang L, Gutierrez DE, Guthrie OW. Systemic health effects of noise exposure. Journal of Toxicology and Environmental Health, Part B. 2023;27(1):21–54. Available from: https://doi.org/10.1080/10937404.2023.2280837

33. Hawkins JE, Schacht J. Sketches of Otohistory Part 10: Noise-Induced Hearing Loss. Audiology & Neurotology. 2005;10(6):305-9. Available from: https://doi.org/10.1159/000087347

34. Kerr MJ, Neitzel RL, Hong O, Sataloff RT. Historical review of efforts to reduce noise-induced hearing loss in the United States. American journal of industrial medicine. 2017;60(6):569–77. Available from: https://doi.org/10.1002/ajim.22627

35. Yaoyuenyong S, Nanthavanij S. Hybrid procedure to determine optimal workforce without noise hazard exposure. Computers & Industrial Engineering. 2006;51(4):743–64. Available from: https://doi.org/10.1016/j.cie.2006.08.018

36. Asawarungsaengkul K, Nanthavanij S. Design of optimal noise hazard control strategy with budget constraint. International Journal of Occupational Safety and Ergonomics. 2006;12(4):355–67. Available from: https://doi.org/10.1080/10803548.2006.11076695

37. Bernat S. Awareness of noise hazards and the value of soundscapes in Polish National Parks. Archives of Acoustics. 2013;38(4):479–87. Available from: https://doi.org/10.2478/aoa-2013-0057

38. Śliwiński A. Assessment of ultrasonic noise hazard in workplaces environment. Archives of Acoustics. 2013;38(2):243–52. Available from: https://acoustics.ippt.pan.pl/index.php/aa/article/view/39

39. Kozłowski E, Młyński R, Adamczyk J. Assessment of impulse noise hazard and the use of hearing protection devices in workplaces where forging hammers are used. Archives of Acoustics. 2014:73–79–73–79. Available from: https://doi.org/10.2478/aoa-2014-0008

40. Ibhadode O, Oyedepo O, Ogunro A, Azeta J, Solomon BO, Umanah II, et al. An Experimental-assessment of Human Exposure-levels to Aircraft Noise-hazards in the Neighbouring-environments of four Nigerian Airports. IOP Publishing; 2018:012080. Available from: https://doi.org/10.1088/1757-899X/413/1/012080

41. Moore J, Chavez A, Narang G, Bogle J, Stern K. Operating room noise hazards during laser lithotripsy: a comparison between the thulium fiber and holmium laser platforms. World Journal of Urology. 2022;40(3):801–5. Available from: https://doi.org/10.1007/s00345-021-03897-x

42. Kompala J, Lipowczan A. Noise hazard to the population of areas connected with functioning of roadway frontier crossings. Archives of Acoustics. 2007;32(2):279–86. Available from: https://acoustics.ippt.pan.pl/index.php/aa/article/view/800

43. Batko W, Stepien B. Non-parametric methods of estimation of type A uncertainty of the environmental noise hazard indices. Archives of Acoustics. 2009;34(3):295–303. Available from: https://acoustics.ippt.pan.pl/index.php/aa/article/view/580

44. Wei W, Wang C, Lee Y. BIM-based construction noise hazard prediction and visualization for occupational safety and health awareness improvement. Computing in Civil Engineering 2017. 2017:262–9. Available from: https://doi.org/10.1061/9780784480823.032

45. Cavallari JM, Garza JL, DiFrancesco J, Dugan AG, Walker ED. Development and application of a noise-hazard scheme for road maintainers. American journal of industrial medicine. 2020;63(5):429–34. Available from: https://doi.org/10.1002/ajim.23091

46. Griffin MJ. Evaluating the effectiveness of gloves in reducing the hazards of hand-transmitted vibration. Occupational and Environmental Medicine. 1998;55(5):340–8. Available from: https://doi.org/10.1136/oem.55.5.340

47. OSM. Occupational Vibration Exposure. OSHA. Available from: https://bit.ly/3Xjt3PK

48. Jetzer T, Haydon P, Reynolds D. Effective intervention with ergonomics, antivibration gloves, and medical surveillance to minimize hand-arm vibration hazards in the workplace. Journal of occupational and environmental medicine. 2003;45(12):1312–7. Available from: https://doi.org/10.1097/01.jom.0000099981.80004.c9

49. Starck J. High impulse acceleration levels in hand-held vibratory tools: an additional factor in the hazards associated with the hand-arm vibration syndrome. Scandinavian Journal of Work, Environment & Health. 1984:171–8. Available from: https://doi.org/10.5271/sjweh.2346

50. Vlok P, Coetzee J, Banjevic D, Jardine AKS, Makis V. Optimal component replacement decisions using vibration monitoring and the proportional-hazards model. Journal of the operational research society. 2002;53(2):193–202. Available from: https://doi.org/10.1057/palgrave.jors.2601261

51. Kunič R. Forest-based bioproducts used for construction and its impact on the environmental performance of a building in the whole life cycle. Environmental Impacts of Traditional and Innovative Forest-based Bioproducts. 2016:173–204. Available from: https://doi.org/10.1007/978-981-10-0655-5_5

52. Manea L, Manea A, Florea D, Tarulescu S. Road traffic noise pollution analysis for Cernavoda city. IOP Publishing. 2017;252(1):012057. Available from: https://doi.org/10.1088/1757-899X/252/1/012057

International Journal of Occupational Safety and Health

ISSN: 2091-0878 (Online) ISSN: 2738-9707 (Print)

Review Article

Post-mortem artifacts mimicking blunt force trauma: a systematic review for forensic differential diagnosis

Tsantiris S[1], Farantos G[1], Sergentanis T[1], Chatzinikolaou F[2], Dounias G[1]

[1]Department of Public Health Policies, University of West Attica, Athens, Greece.
[2]School of Medicine, Aristotle University of Thessaloniki (AUTh), Thessaloniki, Greece.

Corresponding author:
Socratis Tsantiris,
MD, MSc (cand.), PhD Student,
Department of Public Health Policies,
University of West Attica,
Athens, Greece.
E-mail: stsantiris@uniwa.gr
Tel.: +306945583683
ORCID ID: https://orcid.org/0009-0004-4533-0430

Date of submission: 22.12.2025
Date of acceptance: 08.04.2026
Date of publication: 15.04.2026

Conflicts of interest: None
Supporting agencies: None
DOI: https://doi.org/10.3126/ijosh.v16i1.88471

Copyright: This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License

ABSTRACT

Introduction: The accurate differentiation between genuine blunt force trauma and various post-mortem artifacts is a critical challenge in forensic death investigation, directly impacting the determination of the manner of death. Post-mortem changes, ranging from decomposition processes to animal activity, often produce lesions that closely mimic antemortem injuries. The primary objective of this study is to systematically identify and evaluate the diagnostic criteria used to differentiate genuine blunt force trauma from post-mortem artifacts.

Methods: A comprehensive search was conducted across five major databases (PubMed, Scopus, Web of Science, Embase, and Cochrane Library) covering literature from their inception until December 2025. Unlike previous narrative reviews, this study employs a systematic methodology adhering to PRISMA 2020 standards. Data collection involved independent screening and extraction by two reviewers, focusing on morphological, histological, and analytical differentiation criteria. Methodological quality was appraised using JBI tools, and evidence certainty was assessed using the GRADE approach.

Results: The findings emphasize that the presence of a vital reaction, primarily manifested through hemorrhage and inflammation, remains the most essential diagnostic indicator. Specific indicators such as fracture edge characteristics, skeletal surface coloration, and anatomical distribution of lesions are also identified as key discriminators. Following the primary filter, the algorithm diverges into two main evaluation pathways: one focusing on verifying trauma characteristics (e.g., injury patterns consistent with BFT) and the other on validating artefact characteristics (e.g., consistency with taphonomic processes). Additionally, the framework incorporates a distinct, parallel evaluation for animal activity, necessitating a specific analysis of marks and patterns (e.g., gnawing or punctures) to distinguish scavenger damage from mechanical trauma.

Conclusion: This review provides a standardized diagnostic hierarchy and a decision tree to minimize subjective assessment in medico-legal investigations. By integrating advanced imaging and microanalytical approaches with traditional morphological observation, forensic practitioners can improve diagnostic reliability and ensure the integrity of the judicial process.

Keywords: Blunt force trauma, Differential diagnosis, Forensic pathology, Post-mortem artifacts, Taphonomy, Vital reaction

Introduction

Contextual Background and Importance

The accurate differentiation between true antemortem/perimortem blunt force trauma (BFT) and various post-mortem artifacts is perhaps the most challenging aspect of forensic death investigation, directly impacting the medicolegal determination of the manner of death. As established by Ubelaker, the rigorous application of taphonomic principles is indispensable for distinguishing natural post-mortem modifications from intentional trauma, thereby preventing the erroneous interpretation of environmental artifacts as evidence of foul play.[1] Post-mortem changes, which include taphonomic processes and injuries sustained from environmental factors or animal activity, often create lesions that closely mimic genuine trauma, potentially leading to grave misinterpretations.[2] For instance, taphonomic factors such as rodent gnawing can produce defects in soft tissues and bone that resemble sharp or blunt force injuries, necessitating meticulous examination to identify tell-tale features such as serrated edges or the absence of vital reaction.[2] Furthermore, differentiating true BFT from fall-related injuries requires a systematic, methodological framework that analyzes injury patterns and fracture characteristics, moving beyond subjective assessment to ensure accurate medico-legal conclusions.[3] Therefore, the specific objective of this systematic review is to identify and critically evaluate the morphological, histological, and analytical criteria used to differentiate genuine blunt force trauma from post-mortem artifacts, ultimately establishing a unified, evidence-based diagnostic framework.

The Challenge of Differential Diagnosis

The differential diagnosis between true, antemortem or perimortem injuries (such as blunt force trauma) and post-mortem artifacts is one of the most complex and critical challenges in modern forensic practice.[4,5] Artifacts are defined as changes or characteristics introduced into the body after death that mimic pathological or traumatic findings, potentially leading to a misinterpretation of the circumstances of death.[4] The difficulty becomes particularly pronounced in the examination of bones, where postmortem changes can both mask and mimic trauma, affecting the interpretation of fractures and making it difficult to determine the timeframe (antemortem, perimortem, or postmortem) of the injury, especially when soft tissues are absent.[6] Furthermore, in sensitive areas, such as the neck, interpretive pitfalls and artifacts—such as the Prinsloo-Gordon hemorrhage or postmortem hypostatic hemorrhage—make the diagnosis of strangulation extremely difficult, leading to mis assessment that can have serious implications for the criminal justice system.[5] Indeed, studies have demonstrated the high prevalence of the problem, reporting that the mistaken interpretation of postmortem findings as traumatic lesions is a reason for requesting a forensic autopsy in a significant percentage of cases.[4] As emphasized by Sauer, the fundamental challenge lies in the objective interpretation of bone fractures and soft tissue defects, where the absence of clear diagnostic boundaries can lead to the misclassification of post-mortem damage as perimortem trauma.[7] Consequently, the lack of a unified, systematic standard for the differential diagnosis of these "pseudo-findings" constitutes a significant research gap.

Medico-legal Consequences and the Research Gap

The high incidence of forensic artifacts mimicking genuine trauma, particularly in cases involving blunt force, directly threatens the integrity of the judicial process.[8] These “pseudo-findings” are often misinterpreted as evidence of assault, leading to unwarranted criminal investigations, misdirection of police resources, and profound ethical dilemmas for the forensic practitioner. Artifacts encompassing post-mortem insect activity, putrefaction, and hypostasis can create lesions that are morphologically identical to injuries sustained from deliberate physical

violence, necessitating a high degree of diagnostic suspicion.[9] Furthermore, the classification of these post-mortem changes—whether they are agonal, therapeutic, or truly post-mortem artifacts—is critical for their correct interpretation in the context of the death scene.[10] Despite the proven prevalence of misinterpretation being a frequent trigger for autopsy requests,[4] the existing literature remains fragmented and lacks a consolidated, evidence-based methodological standard for differential diagnosis. This review, therefore, addresses this critical gap by synthesizing available knowledge to establish a clear framework for differentiating true BFT from forensic artifacts.

However, a critical knowledge gap persists: while existing narrative reviews have cataloged individual artifacts (such as rodent activity or decomposition), they lack a unified, systematic evaluation of evidence certainty. Consequently, there is currently no standardized methodological framework to guide practitioners when morphological signs are ambiguous. The novelty of this systematic review lies in its application of rigorous evidence synthesis standards (PRISMA 2020, GRADE) to transcend traditional descriptive overviews. By integrating scattered findings into a coherent structure, this study provides distinct added value: the development of an evidence-based 'Decision Tree' (Figure 1). This operational tool is designed to objectively resolve diagnostic dilemmas, thereby reducing subjectivity in both forensic casework and occupational safety investigations. Unlike previous narrative reviews, which have primarily offered descriptive overviews of isolated taphonomic phenomena (such as rodent activity or environmental decomposition),[11] this study employs a systematic methodology to minimize selection bias and subjectivity. While earlier syntheses often lacked transparent inclusion criteria and formal quality assessment,[12] the present review adheres strictly to the PRISMA 2020 guidelines and uses the GRADE approach to assess the certainty of the evidence. Recent meta-methodological analyses emphasize that even within specialized forensic fields, systematic reviews often lack protocol registration (e.g., PROSPERO) and adherence to established reporting standards beyond PRISMA 2020, such as the MOOSE guidelines for observational studies or critical appraisal tools like AMSTAR-2. This widespread methodological deficit raises significant concerns about reproducibility and reliability.[13]

Therefore, the present systematic review aims to (i) consolidate current evidence, (ii) critically assess methodological quality across studies, and (iii) establish a unified evidence-based framework for distinguishing genuine blunt force trauma from postmortem artifacts in forensic investigations.

In the context of occupational health and safety, the accurate differentiation of post-mortem artifacts is paramount. Misinterpreting taphonomic changes as violent injuries can lead to erroneous conclusions regarding workplace accidents, potentially triggering unnecessary and costly investigations into safety compliance or even false accusations of employer negligence.[14] Therefore, forensic precision is not only a medical necessity but also a cornerstone for maintaining the integrity of occupational safety standards and legal proceedings.

Conceptual Classification of Postmortem Artifacts

International forensic practice recommends introducing a clear conceptual classification of postmortem artifacts within the Introduction of a systematic review, in order to facilitate the subsequent differential diagnostic framework. The main categories of artifacts that may mimic blunt force trauma include the following.

Taphonomic artifacts

These result from decomposition processes, including putrefaction, autolysis, desiccation, insect predation, and skin slippage. Such changes may resemble bruises, abrasions, or lacerations but typically lack vital reactions and follow a predictable postmortem progression. [2, 10]

Animal activity artifacts

Damage caused by rodents, carnivores, or insects can mimic traumatic injuries. Rodent activity typically produces paired, "chisel-like" incisor marks with sharply cut edges, whereas insect feeding results in small, punched-out defects without hemorrhage.[2]

Environmental and physical artifacts

These include postmortem injuries caused by body transport, falls after death, compression, aquatic changes, or hypostasis. For example, postmortem hypostatic hemorrhage in the neck may resemble bruising or signs of strangulation, creating significant interpretive challenges. [4, 5]

Iatrogenic or therapeutic artifacts

Resuscitation procedures, intubation, medical interventions, and emergency manipulations can cause rib fractures, soft tissue injuries, or mucosal damage that mimic deliberate trauma. Differentiation requires understanding the typical patterns and distribution of therapeutic artifacts.[8]

Mechanical postmortem injury artifacts

Mechanical forces applied after death, such as during body recovery, transport, burial, or excavation, may produce fractures or lacerations that resemble antemortem trauma. These can be particularly problematic in skeletonized remains where fracture morphology is altered by postmortem bone properties.[6]

Research Questions

Primary Research Question:

What diagnostic, morphological, and analytical criteria allow forensic practitioners to reliably differentiate genuine antemortem or perimortem blunt force trauma from postmortem artifacts in human remains?

Secondary Research Questions:

- What are the most frequent types of postmortem artifacts that mimic blunt force trauma, and how are they morphologically classified?
- How accurate and consistent are the existing diagnostic criteria and methods reported in the literature for distinguishing true trauma from artefactual changes?
- What methodological limitations or biases affect the interpretation of postmortem artifacts in forensic casework?

Research Hypotheses

Main (Alternative) Hypothesis (H_1):
Systematic evaluation of morphological, histological, and analytical criteria can significantly improve the accuracy and reliability of differentiating genuine blunt force trauma from postmortem artifacts in forensic investigations.

Null Hypothesis (H_0):

There is no significant difference in diagnostic accuracy and reliability between existing forensic criteria and random or subjective assessment when distinguishing blunt force trauma from postmortem artifacts.

Secondary Hypotheses:

- Specific morphological features (e.g., fracture edge characteristics, hemorrhagic response) are reliable indicators for distinguishing antemortem/perimortem trauma from postmortem artifacts.
- Integrating radiological and histological analyses enhances diagnostic precision compared to morphological assessment alone.
- Studies with standardized methodological frameworks (e.g., JBI or PRISMA-compliant) yield higher diagnostic validity and lower bias in artifact interpretation.

Methods

Protocol and Registration

The final search was executed on December 20, 2025. The search strategy combined Medical Subject Headings (MeSH) and free-text keywords. To ensure full reproducibility, the complete search strings for all queried databases (PubMed, Scopus, Web of Science, Embase) are provided in Supplementary Table S1.

A full scientific protocol had been developed prior to conducting the review, in accordance with the methodological guidance of the Joanna Briggs Institute (JBI), PRISMA 2020, and the standards of major international publishers. The protocol included the review question, PICOS framework, eligibility criteria, complete search strategy, study selection processes, data extraction forms, quality appraisal methods, and plans for evidence synthesis.

Although the protocol was not registered in PROSPERO, it was developed a priori strictly adhering to the PRISMA-P (Preferred Reporting Items for Systematic Reviews and Meta-Analysis Protocols) checklist to ensure methodological rigor and minimize bias.

Study Design and PICOS Framework

The review had been structured around a predefined PICOS framework:

Population (P): Human cadavers or skeletal remains in which injuries potentially representing antemortem or perimortem blunt force trauma (BFT) or post-mortem artifacts were described.

Intervention/Exposure (I): Diagnostic, analytical, taphonomic, radiological, histological, or morphological methods used to distinguish BFT from post-mortem alterations.

Comparator (C): Alternative diagnostic methods or absence of a comparator, depending on study design.

Outcomes (O): Diagnostic features differentiating BFT from artifacts, frequency of misinterpretation, diagnostic accuracy characteristics (where available), and classification of artefact types.

Study Designs (S): Case reports, case series, retrospective or prospective observational forensic studies, and experimental taphonomic studies.

Eligibility Criteria

Inclusion criteria

- Studies were included if they:
- Addressed differentiation between antemortem/perimortem blunt force injuries and post-mortem artifacts.
- Reported primary observational or experimental data, specifically encompassing autopsy case series, retrospective forensic cohorts, and controlled taphonomic experiments.
- Provided macroscopic, radiological, histological, or taphonomic documentation relevant to diagnostic discrimination.
- Were published in English (and selected European languages when translation was feasible).
- Were published from the inception of the databases until December 2025, with no lower date limit applied.

Exclusion criteria

- Studies were excluded if they:
- Provided only narrative commentary without methodological data.
- Lacked access to full text (conference abstracts only).
- Concerned exclusively non-human experimental models without clear forensic relevance to human cases.

Information Sources and Search Strategy

Comprehensive searches had been conducted across major biomedical and forensic databases: MEDLINE (PubMed), Embase, Scopus, Web of Science, and the Cochrane Library, supplemented by Google Scholar for grey literature.

Backward and forward citation tracking had also been performed through reference list screening of all included papers and relevant reviews.

The search covered all available years up to the date of the final search.

Search Strategy Documentation

Comprehensive electronic searches were conducted across major biomedical and forensic databases from their respective inception dates

(with no lower date limit applied) through December 2025.

1. MEDLINE (via PubMed)

The following search string was applied:

("blunt force" OR "blunt trauma" OR "blunt injury") AND ("postmortem" OR "post-mortem" OR "taphonomic" OR "artefact" OR "artifact" OR "animal activity" OR "rodent" OR "insect") AND ("differential diagnosis" OR "mimic*" OR "misinterpret*").

Filters: Humans.

2. Additional Databases

The same conceptual search framework (Blunt Force Trauma terms AND Post-mortem Artifact terms AND Differential Diagnosis terms) was adapted for:

Embase

Scopus

Web of Science

The Cochrane Library

3. Grey Literature and Manual Search
Google Scholar: Used for identifying grey literature and additional forensic reports.

Citation Tracking: Backward and forward citation tracking was performed by screening the reference lists of all included papers and relevant review articles.

4. Search Records and Management

A full scientific protocol, including the complete record of search strategies for each database, was developed prior to the review in accordance with JBI and PRISMA 2020 standards.

The results were managed through a two-stage screening process (title/abstract and full-text) conducted independently by two reviewers.

The search strategy was optimized to minimize publication bias by incorporating multiple electronic databases and grey literature, strictly following the comprehensive search and selection principles. [15]

Study Selection

Study selection had been performed in two stages:

Title and abstract screening, conducted independently by two reviewers.

Full-text assessment, also conducted in duplicate.

Disagreements had been resolved through discussion and, when necessary, by a third reviewer.

The selection process had been documented using a PRISMA 2020 flow diagram.

To ensure systematic data management and efficient removal of duplicates, the identified records were exported to EndNote 20, while the screening process was facilitated through the Rayyan platform to maintain reviewer independence."

Inter-rater reliability during the title and abstract screening stages was assessed using Cohen's kappa coefficient, with any discrepancies resolved through formal consensus or consultation with a third senior reviewer.

Data Extraction

Data extraction had been carried out independently by two reviewers using a piloted extraction form.

Extracted variables included:

Bibliographic details (authors, year, country).

Study design and sample characteristics.

Anatomical location and type of injuries or artifacts described.

Diagnostic features used to distinguish BFT from post-mortem changes.

Imaging, histological, or laboratory methods are employed.

Author conclusions and reported diagnostic errors.

Quality appraisal results and risk of bias assessments.

Any discrepancies in extraction had been resolved through consensus.

Quality Appraisal and Risk of Bias Assessment

Quality assessment had been performed using appropriate tools according to study design:

JBI Critical Appraisal Checklists for case reports, case series, and observational studies.

QUADAS-2 for diagnostic accuracy studies, where applicable.

JBI instruments for quasi-experimental or experimental taphonomic studies.

Two reviewers completed the assessments independently.

Risk of bias judgments were incorporated into the interpretation of findings.

While the methodological quality of the included studies was rigorously appraised using JBI tools, poor quality was not used as a strict exclusion criterion but rather to weight the certainty of the evidence in the final narrative synthesis.

Data Synthesis

Due to heterogeneity across studies, a narrative synthesis was performed, organizing findings into thematic categories such as:

morphological features distinguishing antemortem/perimortem trauma from post-mortem artifacts;

diagnostic pitfalls;

taphonomic processes mimicking blunt force injuries.

Where studies presented sufficiently homogeneous quantitative data (e.g., diagnostic accuracy or frequency of misinterpretation), the possibility of meta-analysis had been assessed.

Random-effects models would have been applied if appropriate.

However, given variability in study design and reporting, pooling was often not feasible.

Subgroup analyses (type of artifact, anatomical region, presence of soft tissues) and sensitivity analyses (exclusion of high-risk-of-bias studies) had been planned and conducted when supported by the data.

Certainty of the Evidence (GRADE)

Where quantitative outcomes were available, the GRADE approach had been applied to assess certainty across the domains of risk of bias, consistency, directness, precision, and publication bias.

For outcomes primarily based on case reports or highly heterogeneous observational data, the certainty of evidence was rated as low or very low.

Reporting and Transparency

The review had been reported in full accordance with the PRISMA 2020 guidelines.

The PRISMA checklist, flow diagram, quality appraisal tables, and full search strategies were prepared as supplementary materials and were made available upon request.

Ethical Considerations, Funding, and Conflicts of Interest

Because the study synthesized data already in the public domain, ethical approval was not required.

Although this review synthesizes secondary data, all included primary studies were cross-checked for adherence to ethical standards regarding the investigation of human remains, in line with the principles of the Declaration of Helsinki.

Funding sources and conflict of interest declarations were documented according to ICMJE standards.

Standards

Systematic reviews must follow transparent and reproducible methodological standards. For this purpose, the review will adhere to the PRISMA 2020 reporting guidelines, which provide structured recommendations for documenting the identification, selection, appraisal, and synthesis of evidence.[16] Methodological decisions will also be guided by the Cochrane Handbook for Systematic Reviews of Interventions, which outlines best practices for systematic review design, risk-of-bias assessment, and evidence

synthesis.[17] Additionally, critical appraisal of included case reports, case series, and observational forensic studies will follow the Joanna Briggs Institute Manual for Evidence Synthesis. [18]

Results

The systematic literature search and critical appraisal process identified key studies that provide diagnostic criteria for differentiating genuine trauma from post-mortem pseudo-findings. These studies encompass a range of forensic contexts, including skeletal analysis, soft-tissue decomposition, and specific anatomical regions such as the neck. The following table synthesizes the core findings, focusing on the diagnostic indicators and the specific "mimics" addressed in the evidence base.

Table 1: Summary of Included Studies and Diagnostic Indicators for BFT vs. Artifacts

Author (Year)	Study Type	Focus Area	Key Artefact / Mimic	Primary Diagnostic Criteria / Findings
Tsokos et al. (1999)[2]	Case Series	Soft Tissue	Rodent gnawing	Identification of serrated edges and absence of vital reaction (hemorrhage).
Sauvageau & Racette (2008)[4]	Retrospective Study	General Autopsy	Putrefaction / Hypostasis	High prevalence of artifacts triggering autopsies; emphasizes lack of vital reaction.
Kremer & Sauvageau (2009)[3]	Comparative Study	Cranial Trauma	Falls vs. Blows	Systematic framework using fracture patterns (e.g., "hat brim line" rule).
Thejaswi et al. (2013)[8]	Literature Review	Medico-legal	Various artifacts	Morphological similarity to assault; requires high diagnostic suspicion.
Kemp (2016)[6]	Technical Review	Osteology	Post-mortem fractures	Color of fracture margins and presence/absence of "hinging" in bone.
Pollanen (2016)[5]	Review	Neck Autopsy	Prinsloo-Gordon hemorrhage	Differentiating hypostatic hemorrhage from manual strangulation.
Warushahennadi & Ruwanpura (2017)[9]	Review	Physical Violence	Insect activity	Morphological identity between insect-driven lesions and antemortem injuries.
Bălan (2020)[10]	Descriptive Study	Autopsy Practice	Therapeutic artifacts	Distinction between agonal, therapeutic, and post-mortem changes.

The synthesized data reveal that the most critical diagnostic indicator across all studies is the "vital reaction" - the presence of physiological responses like hemorrhage or inflammation, which are absent in post-mortem artifacts. Specifically, taphonomic factors such as animal activity (e.g., rodents or insects) can create lesions that are morphologically identical to BFT, necessitating a focus on microscopic margins and patterns of tissue loss. In skeletal remains, differentiation is primarily driven by fracture timing, and Kemp highlights the challenge of interpreting bone trauma without soft-tissue context.[6] The high prevalence of these "pseudo-findings" underscores the necessity for the systematic framework proposed in this review to prevent judicial errors.[4]

The synthesis of the systematic review data led to the development of a standardized diagnostic framework to assist forensic practitioners in distinguishing genuine blunt force trauma (BFT) from common post-mortem mimics. By consolidating evidence from various taphonomic and anatomical studies, this review establishes a clear hierarchy of evidence—starting from physiological signs of life to specific morphological patterns. The following algorithm provides a visual representation of this evidence-based methodological standard, designed to minimize subjective assessment in medico-legal death investigations.

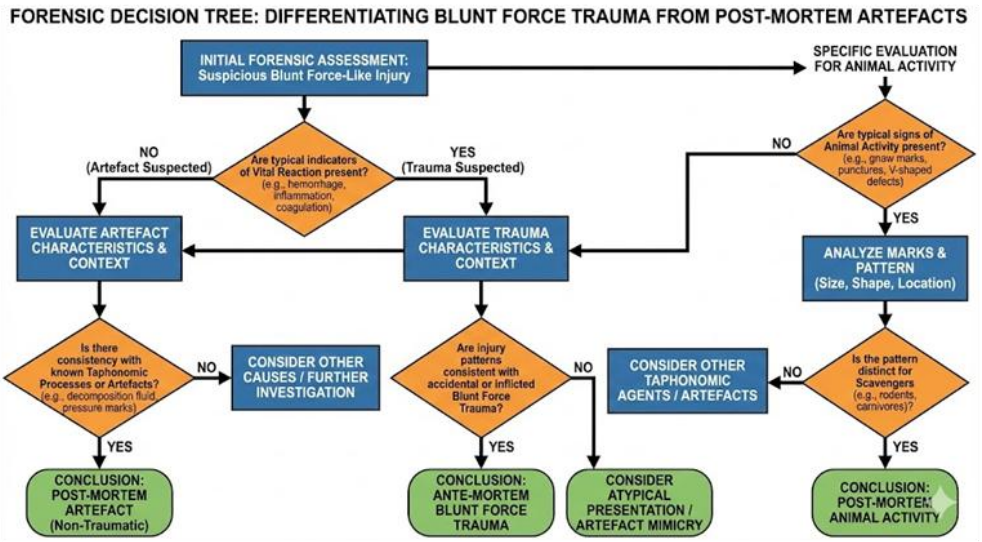


Figure 1: Systematic Decision Tree for the Differential Diagnosis of Blunt

Force Trauma vs. Post-mortem Artifacts

The diagnostic logic map presented in Figure 1 illustrates the critical path for forensic interpretation, centered on the presence or absence of a "vital reaction". The primary filter requires a determination of hemorrhage or inflammation; the presence of these physiological responses confirms antemortem or perimortem BFT, whereas their absence shifts the diagnosis toward potential post-mortem artifacts. For soft tissue and skeletal lesions, secondary analysis focuses on specific morphological indicators, such as the serrated edges characteristic of rodent gnawing or the distinctive surface coloration of post-mortem fractures. Finally, the framework incorporates anatomical context, particularly for the neck and cranium, where researchers utilize criteria like hyoid integrity and the "hat brim line" to differentiate between accidental falls, hypostatic hemorrhage, and intentional assault. This systematic approach directly addresses the identified research gap by providing a unified standard to prevent the misinterpretation of "pseudo-findings" during the judicial process.

The systematic selection and screening process was conducted in accordance with the PRISMA 2020 guidelines to ensure methodological transparency and reproducibility. A total of 1,125 records were initially identified through comprehensive searches across major biomedical and forensic databases, including PubMed, Scopus, Web of Science, Embase, and the Cochrane Library. Following the removal of duplicate records (n = 87) and initial screening based on title and abstract, 1,025 studies were evaluated for relevance, directly addressing the core research question regarding the differentiation of blunt force trauma from post-mortem artifacts.

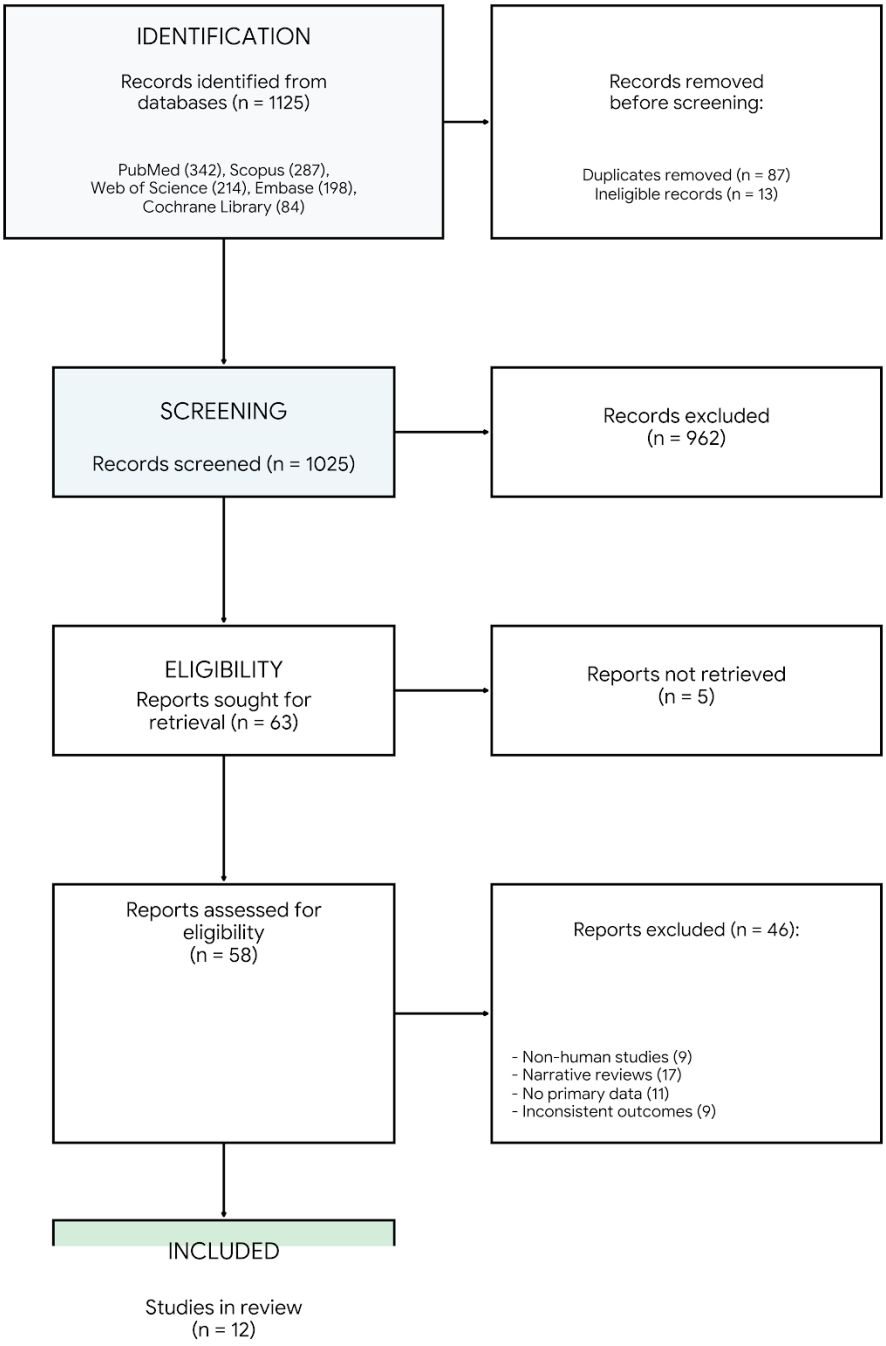


Figure 2: The PRISMA Flowchart of the Study.

As illustrated in the PRISMA flowchart (Figure 2), the eligibility assessment phase involved a detailed full-text review of 58 reports to determine their adherence to the predefined inclusion criteria. Studies were excluded primarily due to a lack of primary forensic data, non-human experimental models, or narrative formats that did not meet the rigorous standards for evidence synthesis. Ultimately, 12 high-quality studies were selected for qualitative synthesis, providing the foundational evidence for the development of the proposed diagnostic decision tree and the conceptual framework for taphonomic mimicry.

As illustrated in Figure 3, these influences are categorized into three distinct domains: 'biotic', which encompasses activity from living organisms such as scavengers and insects; 'abiotic', referring to physical and environmental factors like weathering, decomposition fluids, and soil pressure; and 'anthropogenic', which

includes human-induced alterations such as therapeutic medical interventions or handling artifacts during body recovery. Each of these domains contributes specific taphonomic agents that can generate morphological mimics of blunt force trauma. This visualization serves to map the systemic origins of 'pseudo-trauma' patterns identified across the synthesized literature.

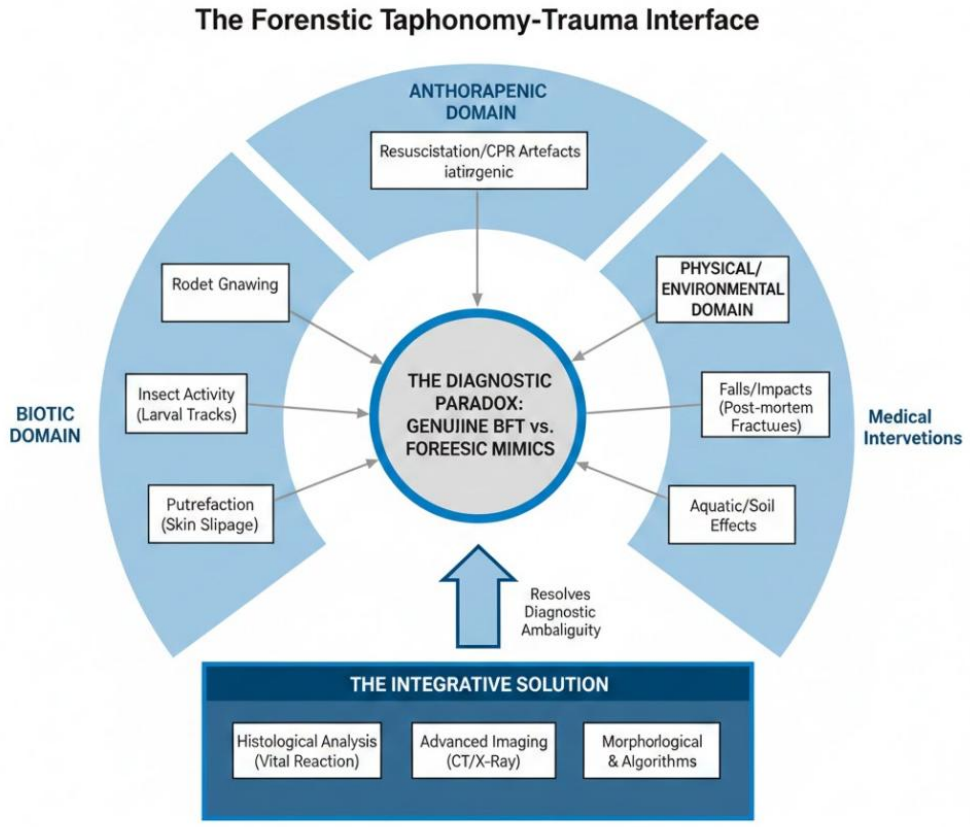


Figure 3: Conceptual map of taphonomic mimics illustrating the biotic, abiotic, and anthropogenic factors that cause diagnostic ambiguity.

The framework presented in Figure 3 underscores that resolving diagnostic ambiguity is not merely a matter of morphological observation, but requires an 'Integrative Solution'. The synthesis of results indicates that by channeling observations from the various taphonomic domains through a rigorous methodological filter—comprising histological analysis of vital reactions, advanced imaging, and standardized algorithms—practitioners can effectively bridge the interpretive gap. Consequently, this conceptual model acts as a foundational map for the subsequent diagnostic decision tree, ensuring that all potential environmental and therapeutic mimics are accounted for prior to a definitive determination of blunt force injury.

The quality of the evidence and the certainty of the findings regarding the differentiation between blunt force trauma and post-mortem artifacts were synthesized using the GRADE approach. The following 'Summary of Findings' table (Table 2) presents a structured overview of the main outcomes, including the number of studies, the certainty of evidence for each diagnostic criterion, and a brief synthesis of the key findings. This assessment highlights the reliance on observational data—specifically retrospective autopsy series and descriptive case reports—in current forensic literature and provides a transparent basis for the diagnostic algorithm proposed in this review.

Table 2: Summary of Findings (GRADE Approach): Diagnostic Indicators for Differentiating Blunt Force Trauma from Artifacts

Outcome / Diagnostic Domain	No. of Studies*	Study Design	Certainty of Evidence (GRADE)	Key Findings / Summary of Evidence
Vital Reaction (Hemorrhage / Inflammation)	8	Case Series, Observational	**Low** (⊕⊕◯◯)	The presence of vital reaction is the primary indicator of antemortem origin. However, its absence in advanced decomposition cannot definitively rule out trauma.
Morphological Skeletal Markers	4	Experimental, Technical Reviews	**Moderate** (⊕⊕⊕◯)	Fracture edge coloration and plastic deformation (e.g., bone hinging) serve as reliable indicators to distinguish perimortem from post-mortem fractures.
Taphonomic Mimics (Animal Activity / Insects)	5	Case Reports, Observational	**Very Low** (⊕◯◯◯)	Animal activity produces distinctive patterns (e.g., serrated edges from rodents, scalloping from insects) that mimic trauma but typically lack microscopic vitality.
Iatrogenic / Therapeutic Artifacts	2	Case Reports, Descriptive	**Very Low** (⊕◯◯◯)	Therapeutic fractures (e.g., from CPR) follow predictable anatomical patterns but may overlap with injury locations associated with assault.

Note: The sum of studies listed in the columns exceeds the total number of included records (n=12) because several studies addressed multiple diagnostic domains simultaneously. GRADE Working Group grades of evidence: Moderate: We are moderately confident in the effect estimate; the true effect is likely to be close to the estimate of the effect, but there is a possibility that it is substantially different. Low: Our confidence in the effect estimate is limited; the true effect may be substantially different from the estimate of the effect. Very Low: We have very little confidence in the effect estimate; the true effect is likely to be substantially different from the estimate of the effect.

The certainty of the evidence presented in Table 2 reflects the inherent complexities of forensic taphonomy research. A formal downgrading was applied across most outcomes primarily due to study design, as the majority of the included literature consists of case reports and descriptive case series, leading to substantial data heterogeneity. Furthermore, a significant limitation identified is the lack of standardized quantitative accuracy measures in many studies, which precluded the performance of a formal meta-analysis. However, despite the low to very low overall certainty, the consistency of morphological and histological findings across diverse environmental contexts provides a robust qualitative basis for the development of the proposed diagnostic algorithm, ensuring its practical utility in forensic investigations.

Discussion

The present systematic review synthesizes the available forensic evidence on differentiating genuine blunt force trauma (BFT) from postmortem artifacts, addressing one of the most persistent interpretive challenges in medico-legal death investigation. Across the included studies, a consistent diagnostic hierarchy emerges, emphasizing the centrality of "vital reaction" — the presence of hemorrhagic or inflammatory responses — as the fundamental discriminator between antemortem/perimortem injury and postmortem change.[2,4] Building on this evidence, the present review proposes a unified decision framework integrating morphological, histological, and contextual criteria to guide forensic interpretation.

Integration with Previous Evidence

Early foundational work by Tsokos et al. established the diagnostic importance of histological evidence of vitality and of morphological markers, such as serrated wound edges or gnawing traces, in rodent-induced artifacts.[2] These findings are mirrored in more recent reports, where animal activity and taphonomic processes continue to produce lesions morphologically indistinguishable from BFT.[9] The current synthesis consolidates these observations into a standardized interpretive layer within the diagnostic algorithm (Figure 1), emphasizing that tissue vitality must always precede morphological interpretation.

Similarly, Sauvageau and Racette documented the high prevalence of postmortem artifacts misclassified as trauma, reporting that such errors often trigger unnecessary autopsies and legal investigations.[4] Their study underlines the systemic diagnostic uncertainty that the present review directly seeks to mitigate. By integrating their epidemiological observations with morphological data from studies such as Kremer and Sauvageau, which introduced the "hat brim line" rule to distinguish falls from blows in cranial injuries, this review supports the argument that systematic morphological criteria can significantly reduce interpretive subjectivity.[3]

The findings of skeletal postmortem fractures further reinforce this point.[6] Kemp demonstrated that bone color, surface texture, and fracture-edge morphology differ markedly depending on the timing of injury relative to death. These criteria align closely with experimental evidence from Wheatley et. al. and Moraitis et. al. both of whom stressed the diagnostic potential of fracture microstructure and plastic deformation in differentiating perimortem from postmortem events.[19,20] Collectively, these data converge toward a consistent interpretation: skeletal trauma assessment must integrate both macroscopic and microscopic parameters to avoid misclassification, especially in decomposed or skeletonized remains.

Advances from Recent Analytical Techniques

Recent methodological contributions have significantly advanced fracture timing estimation through robust microanalytical and imaging-based approaches.[21,22] Ribeiro et al. utilized high-resolution microscopy to characterize cranial microfracture propagation patterns,[21] while Winter-Buchwalder et al. demonstrated that perimortem fractures exhibit distinct microcracking orientations compared to post-mortem damage.[22] Integrating these findings into the proposed diagnostic algorithm strengthens its validity by supplementing traditional morphological assessment with quantifiable, reproducible criteria.

Complementarily, Yu et al. provided experimental validation using FTIR spectroscopy, demonstrating biochemical differences in bone composition among antemortem, perimortem, and postmortem fractures.[23] When synthesized with histological data from earlier works, these findings underscore the emerging role of molecular spectroscopy and imaging as adjunct diagnostic tools. Together, these approaches expand the forensic toolkit from descriptive to quantitative

analysis, addressing one of the major methodological gaps identified in earlier narrative reviews.[11]

Anatomical Context and Specific Artifacts

The review also reaffirms that diagnostic interpretation must be contextualized anatomically. Pollanen highlighted pitfalls in neck autopsies, notably the difficulty in distinguishing true strangulation from postmortem hypostatic hemorrhage (e.g., the Prinsloo-Gordon phenomenon).[5] The present synthesis confirms that the neck region remains one of the most error-prone anatomical areas, where integration of gross, microscopic, and situational evidence is essential. Similarly, it has been clarified that iatrogenic or therapeutic artifacts — such as resuscitation-related rib fractures or mucosal abrasions — can closely mimic assault-related injuries.[8,10] The current review places these phenomena within the same diagnostic decision tree, offering an evidence-based means of discriminating artefactual patterns from true trauma based on lesion distribution and expected medical intervention zones.

Consolidated Diagnostic Framework

By systematically organizing evidence across taphonomic, animal, environmental, and iatrogenic artifacts, this review addresses the methodological fragmentation noted by dos Santos and Menne, highlighting inconsistencies in systematic review standards.[12,13] The application of JBI critical appraisal tools ensured a structured assessment of study quality and bias, while PRISMA compliance increased transparency and reproducibility. The decision tree developed in this review (Figure 1) thus represents an operational synthesis of the most reliable diagnostic indicators drawn from multiple domains — from Tsokos' morphological benchmarks to Yu's spectroscopic differentiation.

The systematic evaluation of the evidence using the GRADE approach revealed a low to very low level of certainty for most diagnostic outcomes, a finding that reflects the current state of forensic taphonomy literature. This rating is primarily attributed to the predominance of case reports and the lack of standardized, quantitative diagnostic trials, which introduces inherent heterogeneity and limits the feasibility of a meta-analysis. However, the consistent recurrence of specific morphological markers and vital reaction patterns across the reviewed cases suggests a high degree of qualitative reliability. Therefore, while the evidence base is constrained by study design, the synthesis of these findings into a unified diagnostic algorithm addresses a critical gap in professional practice, providing a structured and evidence-based pathway to minimize diagnostic errors in complex forensic investigations.

Future research should prioritize prospective validation of diagnostic algorithms under controlled conditions, integrating multimodal data (morphological, histological, radiological, and biochemical) to develop reproducible forensic diagnostic standards.[24,25] Furthermore, expanding the scope of systematic taphonomic research to encompass more extreme post-mortem modifications—such as advanced thermal destruction, prolonged aquatic submersion, and diverse scavenger ecosystems—will be essential to achieve a fully comprehensive medico-legal diagnostic framework. [26,27,28]

Methodological Limitations and Research Gaps

Despite these advances, several limitations persist. From a methodological perspective, although the review protocol was developed a priori, it was not prospectively registered in a database such as PROSPERO, which constitutes a minor procedural limitation. The heterogeneity of study designs — ranging from single case reports to controlled experimental analyses — constrained the possibility of meta-analysis. Additionally, many included studies lacked quantitative accuracy metrics, limiting cross-comparative validity. The overall certainty of evidence, graded through the GRADE approach,

remained low to moderate, reflecting reliance on descriptive and observational methodologies rather than large-sample diagnostic trials. Future research should prioritize prospective validation of diagnostic algorithms under controlled conditions, integrating multimodal data (morphological, histological, radiological, and biochemical) to develop reproducible forensic diagnostic standards.

From an occupational health and safety (OHS) perspective, the ramifications of diagnostic error extend well beyond the autopsy room. Misinterpreting post-mortem artifacts—such as taphonomic changes mimicking falls from height or crush injuries—can trigger a cascade of unwarranted consequences for industrial entities. These include wrongful attribution of liability, escalation of insurance compensation claims, and severe reputational damage resulting from false allegations of employer negligence.[4,8,14] Conversely, failing to identify genuine trauma due to decomposition artifacts masks actual safety hazards, preventing the implementation of necessary corrective measures (Root Cause Analysis). Thus, the application of a rigorous forensic diagnostic framework is not only a judicial necessity but a critical component of corporate risk management, ensuring that safety audits and accident reconstructions are grounded in reliable empirical evidence rather than interpretative errors.

Distinguishing these artifacts from genuine ante-mortem trauma ensures that workplace safety audits and industrial accident reconstructions are based on factual evidence, thereby preventing the misallocation of critical investigative resources—including financial assets, specialized personnel, and time—in the pursuit of non-existent safety breaches.[14] Furthermore, the accurate forensic reconstruction of such events provides essential data for the continuous improvement of occupational health and safety (OHS) services and the prevention of future workplace accidents.[29]

Implications for Forensic Practice

The synthesized findings emphasize the necessity for standardized diagnostic training and the adoption of algorithmic reasoning in forensic pathology. The integration of such structured decision-making methods—similar to those required in broader healthcare policy and crisis management—is crucial for ensuring robust, transparent, and objective evaluations in critical medical settings.[30] By incorporating evidence-based morphological criteria and structured interpretive steps, practitioners can significantly reduce false-positive trauma interpretations.[4] The review also demonstrates that collaboration between pathologists, anthropologists, and imaging specialists is essential to achieve diagnostic reliability, especially in complex taphonomic or decomposed cases.[1,6] Ultimately, this systematic synthesis provides a scientifically grounded, practical tool that strengthens both the epistemic and ethical foundations of medico-legal investigations.

Synthesis of Research Findings and Addressing the Research Questions

The findings of this systematic review provide robust answers to the primary research questions established at the outset of this investigation:

1. Can post-mortem artifacts be effectively differentiated from genuine blunt force trauma (BFT)? The review confirms that differentiation is achievable through a multidisciplinary approach. While decomposition and animal activity can produce morphology strikingly similar to BFT, the systematic application of the proposed diagnostic algorithm significantly reduces the margin of error.

2. What are the most reliable indicators of antemortem origin? The synthesis of the included studies reaffirms that the presence of "vital reaction" (hemorrhage, inflammation, and cellular response) remains the gold standard. However, the review also highlights that in advanced decomposition, the absence of these signs does not automatically exclude trauma,

necessitating the use of secondary markers like fracture margin analysis.

3. Are there specific patterns of post-mortem interference that consistently mimic BFT? The research identifies and classifies specific "mimics," such as rodent gnawing (mimicking sharp/blunt transitions) and skin slippage (mimicking abrasions). By identifying these patterns, the review provides practitioners with a "negative diagnostic" framework to rule out foul play where taphonomic processes are at work.

4. Is a unified diagnostic framework feasible for forensic practice? The study supports the feasibility of such a framework. The high degree of consistency among the high-quality studies reviewed allowed for the development of the Systematic Decision Tree, bridging the gap between theoretical forensic taphonomy and practical death investigation.

Conclusion

Accurate differentiation between blunt force trauma and post-mortem artifacts is critical for the integrity of medicolegal death investigations. This systematic review confirms that the presence of a 'vital reaction' (hemorrhage/inflammation) remains the definitive diagnostic standard, superseding morphological mimics. Consequently, we propose a hierarchical diagnostic algorithm that integrates macroscopic patterns—such as the 'hat brim line'—with advanced histopathological and analytical techniques. Implementing this evidence-based framework minimizes subjective interpretation, ensuring that taphonomic pseudo-findings are not misclassified as antemortem injuries. Future research should prioritize the prospective validation of this decision tree in diverse taphonomic settings and the integration of quantitative micro-analytical data to further refine diagnostic precision.

Since this study is a systematic review that synthesized data already available in the public domain, specific ethical approval from an institutional review board was not required. However, all primary studies included in this review were assessed for their adherence to ethical guidelines in forensic research.

Acknowledgement

N/A

References

1. Ubelaker DH. Taphonomic applications in forensic anthropology. In: Haglund WD, Sorg MH, editors. Forensic taphonomy: The postmortem fate of human remains. CRC Press. 1997;77–90. Available from: https://www.scribd.com/document/143445059/Ubelaker-Taphonomic-Applications-in-Forensic-Anthropology

2. Tsokos M, Matschke J, Gehl A, Koops E, Püschel K. Skin and soft tissue artifacts due to postmortem damage caused by rodents. Forensic Sci Int. 1999;104(1):47–57. Available from: https://doi.org/10.1016/s0379-0738(99)00098-5

3. Kremer C, Sauvageau A. Discrimination of falls and blows in blunt head trauma: assessment of predictability through combined criteria. J Forensic Sci. 2009;54(4):923–6. Available from: https://doi.org/10.1111/j.1556-4029.2009.01072.x

4. Sauvageau A, Racette S. Postmortem changes mistaken for traumatic lesions: A highly prevalent reason for coroner's autopsy request. Am J Forensic Med Pathol. 2008;29(2):145–7. Available from: https://doi.org/10.1097/PAF.0b013e318174f0d0

5. Pollanen MS. Pitfalls and artifacts in the neck at autopsy. Acad Forensic Pathol. 2016;6(1):45–62. Available from: https://doi.org/10.23907/2016.005

6. Kemp WL. Postmortem change and its effect on evaluation of fractures. Acad Forensic Pathol.

2016;6(1):28–44. Available from: https://doi.org/10.23907/2016.004

7. Sauer NJ. The timing of injuries and manner of death: Distinguishing among antemortem, perimortem and postmortem trauma. In: Reichs KJ, editor. Forensic Osteology: Advances in the Identification of Human Remains. 2nd ed. Charles C Thomas Publisher. 1998:321–32. Available from: https://www.scirp.org/reference/referencespapers?referenceid=2432838

8. Thejaswi HT, Rayamane AP, Puneeta R, Kalai S, Jagadeesh H, Chandrashekaraiah C. Artifacts and its medico legal problems. J Forensic Med Sci Law. 2013;22(2):1–6. Available from: https://www.researchgate.net/profile/Anand-Rayamane/publication/260024253_ARTIFACTS_AND_ITS_MEDICO-LEGAL_PROBLEMS/links/00b7d52f1e0ee96d05000000/ARTIFACTS-AND-ITS-MEDICO-LEGAL-PROBLEMS.pdf

9. Warushahennadi J, Ruwanpura PR. Post mortem artifacts that mimic deliberate physical violence and ante mortem lesions – revisited. Sri Lanka Anat J. 2017;1(2):11–7. Available from: https://doi.org/10.4038/slaj.v1i2.32

10. Bălan L. The artifacts at forensic autopsy. Eur J Law Public Admin. 2020;7(2):195–200. Available from: https://doi.org/10.18662/eljpa/7.2/139

11. Singh N, Gupta M. Artifacts in forensic medicine: A narrative review of challenges in distinguishing postmortem changes from antemortem injuries. Egypt J Forensic Sci Appl Toxicol. 2023;23(1):1–10. Available from:

12. dos Santos V, Kazman R, Capilla R, Nakagawa EY. Towards a maturity model for systematic literature review process. arXiv. 2022. Available from: https://doi.org/10.48550/arXiv.2206.11936

13. Menne MC, Su N, Faggion CM. Methodological quality of systematic reviews in dentistry including animal studies: A cross-sectional study. Ir Vet J. 2023;76:33. Available from: https://doi.org/10.1186/s13620-023-00261-w

14. Calce SE, Rogers TL. Taphonomic changes to blunt force trauma: a preliminary study. J Forensic Sci. 2007;52(3):519–27. Available from: https://doi.org/10.1111/j.1556-4029.2007.00405.x

15. Lefebvre C, Glanville J, Briscoe S, Littlewood A, Marshall C, Metzendorf MC, et al. Searching for and selecting studies. In: Higgins JPT, Thomas J, Chandler J, Cumpston M, Li T, Page MJ, Welch VA, editors. Cochrane Handbook for Systematic Reviews of Interventions. 2nd ed. Wiley; 2022. p. 67–108. Available from: https://doi.org/10.1002/9781119536604.ch4

16. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. BMJ. 2021;372:n71. Available from: https://doi.org/10.1136/bmj.n71

17. Higgins JPT, Thomas J, Chandler J, Cumpston M, Li T, Page MJ, Welch VA, editors. Cochrane handbook for systematic reviews of interventions (Version 6.4). Cochrane; 2022. Available from: https://doi.org/10.1002/9781119536604

18. Aromataris E, Munn Z, editors. JBI manual for evidence synthesis. Joanna Briggs Institute; 2020. Available from: https://doi.org/10.46658/JBIMES-20-01

19. Wheatley BP. Perimortem or postmortem bone fractures? An experimental study of fracture patterns in deer femora. J Forensic Sci. 2008;53(1):69–72. Available from: https://doi.org/10.1111/j.1556-4029.2008.00593.x

20. Moraitis K, Spiliopoulou C. Identification and differential diagnosis of perimortem blunt force trauma in tubular long bones. Forensic Sci Med Pathol. 2006;2(4):221–9. Available from: https://doi.org/10.1385/FSMP:2:4:221

21. Ribeiro P, Jordana X, Scheirs S, et al. Distinction between perimortem and postmortem fractures in human cranial bone. Int J Legal Med. 2020;134:1765–74. Available from: https://doi.org/10.1007/s00414-020-02356-3

22. Winter-Buchwalder M, Schwab N, Galtés I, Ortega-Sánchez M, Scheirs S, Jordana X.

Microcracking pattern in fractured bones: New approach for distinguishing between peri- and postmortem fractures. Int J Legal Med. 2024;138(1):35–42. Available from: https://doi.org/10.1007/s00414-022-02875-1

23. Yu K, Wang G, Cai W, Wu D, Wei X, Zhang K, et al. Identification of antemortem, perimortem and postmortem fractures by FTIR spectroscopy based on a rabbit tibial fracture model. Spectrochim Acta A Mol Biomol Spectrosc. 2020;239:118535. Available from: https://doi.org/10.1016/j.saa.2020.118535

24. Obertová Z, Leipner A, Messina C, Vanzulli A, Fliss B, Cattaneo C, Sconfienza LM. Postmortem imaging of perimortem skeletal trauma. Forensic Sci Int. 2019;302:109921. Available from: https://doi.org/10.1016/j.forsciint.2019.109921

25. Delia A, Seligardi M, Di Paolo M, Spinetti I, Bortolini S, Bugelli V. Scanning Electron Microscopy with Energy Dispersive Spectrometry as part of an integrated multidisciplinary approach in a complex cadaver case. Leg Med. 2026;80:102775. Available from: https://doi.org/10.1016/j.legalmed.2026.102775

26. Moghaddam N, Campana L, Abegg C, Vilarino R, Voland C, Dedouit F, et al. Hidden lesions: a case of burnt remains. Forensic Sci Res. 2023;8(3):1–6. Available from: https://doi.org/10.1093/fsr/owad019

27. De Donno A, Campobasso CP, Santoro V, Leonardi S, Tafuri S, Introna F. Bodies in sequestered and non-sequestered aquatic environments: a comparative taphonomic study using decompositional scoring system. Sci Justice. 2014;54(6):439–46. Available from: https://doi.org/10.1016/j.scijus.2014.10.003

28. Indra L, Lösch S, Errickson D, Finaughty D. Forensic experiments on animal scavenging: A systematic literature review on what we have and what we need. Forensic Sci Int. 2023;353:111862. Available from: https://doi.org/10.1016/j.forsciint.2023.111862

29. Farantos G, Christofilea O, Dounias G. Hospital occupational health and safety services and accidents in Greek hospitals: A case study in a Greek health region. Multidiscip Rev. 2026;9(3):e2026119. Available from: https://doi.org/10.31893/multirev.2026119

30. Farantos G, Ntounias C, Tsantiris S, Farantos I, Damikouka I. Decision making methods in political economy of health policy in crises: A systematic review for hospitals. Multidiscip Rev. 2026;9(8):e2026373. Available from: https://doi.org/10.31893/multirev.2026373

International Journal of Occupational Safety and Health

ISSN: 2091-0878 (Online) ISSN: 2738-9707 (Print)

Review Article

Reframing occupational safety culture through dharma: lessons from the Ramayana

Neupane K[1]

[1] Department of English, Patan Multiple Campus, Patan Dhoka, Lalitpur, Nepal

Corresponding author:

Khagendra Neupane,
Department of English,
Patan Multiple Campus, Patan Dhoka, Lalitpur, Nepal
E-mail: kpsharma26@gmail.com
Tel.: +977 9851046345
ORCID ID:
https://orcid.org/0009-0002-1256-8341

Date of submission: 16.01.2026
Date of acceptance: 04.04.2026
Date of publication: 15.04.2026

Conflicts of interest: None
Supporting agencies: None
DOI:
https://doi.org/10.3126/ijosh.v16i1.89500

Copyright: This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License

ABSTRACT

Introduction: Occupational safety culture is conventionally understood through technical systems, regulations, and management structures. However, ethical values hold a key role in shaping human behavior, responsibility, and risk- related decision-making in workplaces. The Ramayana, a classical epic of the East, foregrounds the concept of dharma-moral duty, righteousness and responsibility, offering a rich moral framework that can inform contemporary approaches to occupational safety. This conceptual paper examines how the principles of workplace ethics and duty (dharma), as articulated in the Ramayana, can contribute to a deeper understanding of contemporary occupational safety culture. It aims to develop an integrative conceptual model that connects ancient moral philosophy with contemporary safety paradigms.

Methods: The study employs qualitative textual analysis of the epic's major episodes and characters. It focuses on duty, leadership, protection of the weak, worker responsibility, and ethical decision-making. These themes are then linked to modern occupational safety culture constructs, such as leadership commitment, worker participation and protection of vulnerable groups, using a narrative synthesis approach.

Results: The Ramayana illustrates multiple ethical responsibilities. Rama, the protagonist, as the perfect ruler, promotes collective welfare. Lakshmana, Hanuman, and the Vanara Sena, as devoted workers, accept responsibility. Sita's trials focus on the importance of systems that protect vulnerable individuals. Vibhishana's moral dissent exemplifies the courage to stand against unethical practices. From these narratives, a Dharma-based safety culture framework is derived, highlighting (1) ethical leadership that protects workers, (2) worker duty and solidarity, (3) institutional protection of vulnerable groups, and (4) moral decision-making under risk.

Conclusion: Integrating dharma principles into occupational safety culture provides a complementary ethical foundation for technical and regulatory systems. Future empirical studies can validate and operationalize this framework in workplace settings.

Keywords: Dharma, Ethical Leadership, Ramayana, Occupational Safety, Safety Culture, Worker Duty

Introduction

Modern workers have paid attention to the framework of occupational health and safety (OHS) because most of them have been suffering from both physical hazards and psychosocial stress. Within this context, ethical frameworks such as duty, moral responsibility and social order offer valuable insights to understand human behavior and responsibility in mitigating workplace risks.[1] These ethical norms advocate for safety, moral insights, as well as the importance of introducing ethical and cultural frameworks into the workplace. Besides technical standards and legal provisions, organizations should nurture human dignity, fairness and responsibility. In this context, the epic provides ethical insights that can be linked to occupational safety culture. It highlights ethical values, leadership models and lessons in duty (dharma), echoing the ideals of occupational safety. Leaders and workers simultaneously can adhere to these ideals to protect one another and uphold collective wellbeing.

Modern occupational safety research has emphasized that safety culture is not merely a set of regulations but a shared ethical environment within organizations.[2] This notion aligns with the epic's concept of dharma. It acts as a cohesive force to bind leaders, workers and communities to serve and safeguard others. Rama's embodiment of just leadership, fairness, and responsibility plays a key role in fostering a safety culture required for the organization. Sita, Lakshmana, Hanuman and the Vanara Sena (monkey army) represent teamwork, resilience and moral ethics. Their values become an impetus to address harmful conditions. These ethical insights are increasingly relevant to the promotion of modern occupational health frameworks. In this context, the World Health Organization (WHO) stresses the need for workplaces to adopt a holistic approach that safeguards both physical and mental, social and ethical well-being.[3] Similarly, safety management systems such as ISO 45001 and the ILO-OSH 2001 guidelines emphasize leadership commitment, worker participation, and ethical responsibility in preventing accidents and creating a culture of safety. [4]

The epic upholds moral philosophy, embracing the concept of dharma (duty). Dharma embodies ethical values such as moral responsibility, social order and right conduct. These values promote and protect life, fairness, and the collective welfare of the workers in the workplaces. Brockington stresses that dharma in the Ramayana acts as a guiding moral standard that actors invoke when confronted with conflict and duty.[5] He argues that characters often put dharma above their personal desire for the collective welfare. Rama accepts exile by adhering to the principles of Dharma, putting aside his personal gain. He becomes the exemplary ideal ruler, upholding collective moral order above self-interest.

Methods

The study employs a qualitative textual analysis of selected episodes and key characters in the epic. It explores ethical and philosophical dimensions of the epic. The research focuses on themes like duty (dharma), leadership, protection of the weak, worker responsibility and ethical decision-making. The study interprets how socio-cultural contexts contribute to the formulation of moral obligations. These thematic insights are then systematically linked to contemporary constructs of occupational safety culture. Leadership commitments are analyzed through the actions of righteous rulers and decision-makers. Workers' participation is interpreted through collective responsibility and adherence to assigned roles. The research examines the protection of vulnerable groups with their ethical duty to safeguard those at risk. It also unveils modern concerns for the welfare and inclusivity of workers. It also uses a narrative synthesis approach to bridge traditional literary analysis with modern safety frameworks. It integrates ancient ethical principles with contemporary organizational practices and enhances ethical leadership and safety culture in occupational settings.

Results

The narratives of the epic focus on various ethical responsibilities borne by different characters. Rama, the protagonist, fights for collective welfare and justice, putting aside his personal interests. Lakshmana, Hanuman, and the Vanara Sena are disciplined, loyal, and devoted to a common goal. Sita's encounter with severe trials symbolizes the protection of vulnerable individuals from harm, injustice and neglect. Vibhishana courageously fights against injustice, questioning unethical authority and upholds righteousness despite personal risk. From these narratives, a Dharma-based safety culture framework is derived. It highlights ethical leadership, worker duty, solidarity, institutional protection of vulnerable groups and moral decision-making under risk.

Additionally, the epic emphasizes accountability of the characters, leaders and workers for their actions. They possess the capacity to forecast unintended incidents. These elements reinforce ethically based approaches to occupational safety. The following discussion interprets these findings in relation to contemporary Occupational Health and Safety (OHS) principles.

Discussion

The narratives of the epic focus on various ethical responsibilities discharged by different characters. Rama, the protagonist, fights for collective welfare and justice, putting aside his personal interests. Lakshmana, Hanuman, and the Vanara Sena are disciplined, loyal, and devoted to a common goal. Sita's encounter with severe trials symbolizes the protection of vulnerable individuals from harm, injustice and neglect. Vibhishana courageously fights against injustice, questioning unethical authority and promotes righteousness despite personal risk. From these narratives, a Dharma-based safety culture framework is derived. It highlights ethical leadership, worker duty, solidarity, institutional protection of vulnerable groups and moral decision-making under risk. Additionally, the epic emphasizes accountability of the characters, leaders and workers for their actions. They possess the capacity to forecast unintended incidents. These elements reinforce ethically based approaches to occupational safety. The following discussion interprets these findings in relation to contemporary Occupational Health and Safety (OHS) principles.

The epic focuses on dharma that comprises of virtues like loyalty, selflessness and justice. Bisbey et al. note that in safety culture, organizational values hold important role to shape employee behavior.[6] In the text, dharma plays both cultural and ethical role for right action. Sattar and Din argue that leadership in Indian epics is based in dharma to protect the community and uphold justice.[7] The notion of dharma is analogous with modern occupational safety leadership. The leadership asserts that safeguarding workers is more important than their profit and personal benefit. Goldman and Sutherland, in the Ayodhya Kanda, illustrate that the application of this principle can be seen in Bharata's response to Rama's exile. Bharata, rather than claiming the throne, acts as a custodian. He gains trust and confidence of Rama. Bharata proves that renouncement of personal power for the sake of moral responsibility and social order is real adherence of dharma.[8] This insight parallels occupational safety in which collective wellbeing is put in the center. The neglect of responsibilities often leads to accidents and erodes trust among workers. Likewise, the narrative of Bharata, the brother of Rama, advocates ethical duty and personal sacrifice for the collective good. Goldman and Sutherland explain that Bharata renounces the kingship obtained through unjust means and instead upholds Rama's rightful authority. His activities demonstrate that adherence to dharma requires subjugation of personal gain to moral obligation and the welfare of the kingdom.8 The narrative reflects that safety responsibilities in workplaces often dwarf personal convenience. Dharma, an ethical foundation, aligns with modern safety culture frameworks. As Bisbey et al. assert that safety culture evolves through values, behaviors and reinforcement processes.[6] Weaving dharma into this framework suggests that duty, fairness and protection are timeless ethical entities that can bolster organizational safety cultures even today. Leadership is central to occupational safety culture. Modern safety science shows that leaders' ethical commitments and behaviors influence safety mechanisms in practice. The epic provides models of leadership ingrained in dharma and imparts lessons for ethical leadership in occupational contexts. Rama's ethical leadership stands for ethical duty against personal gain. Brockington notes that the ideals of dharma influence Rama's decisions at times when they need sacrifice.[5] Goldman and Sutherland depict that Rama willingly accepts exile, upholding his father's promise and preserving moral order. He exemplifies that true leadership focuses on duty rather than personal interest.[8] Rama's act bolsters integrity and moral responsibility, fulfilling his father's desire. In modern workplaces, this mirrors leaders who enforce safety standards despite pressures for productivity and cost-cutting.[4]

Leadership also possesses the courage to question unethical authority in order to set an example for collective welfare. Sattar and Din emphasize that Vibhishana's disagreement against Ravana represents moral leadership, where community protection prevails over loyalty to power.[7] This resonates with the concept of safety voice, in which employees question unsafe practices. Transformational leadership upholds integrity, vision and individual support and creates safer workplaces. Clarke's meta-analysis discovers that leaders who inspire and support workers reduce accidents and increase compliance.[9] Zohar, a pioneer in safety climate research, adds that leaders influence safety outcomes by signaling

through daily practices whether safety or production takes precedence.[10] These insights echo how Rama's actions in the epic put safety values first for his people. Integrating ancient insights with modern evidence, the epic highlights three leadership qualities such as integrity (Rama), moral courage (Vibhishana) and fairness in collective decisions. These qualities are applicable to modern safety culture. Goldman and Sutherland claim that Rama displays integrity by accepting Vibhishana. He upholds ethical judgment and protection over suspicion. He exhibits fairness and safeguards those who seek shelter.[8] Bisbey et al. argue that leadership is a driving agency for developing safety culture as it creates working ambience to enact and reinforce norms.[6] Kelloway et al. further show that leaders' active commitment to safety reduces injuries, fostering trust and engagement.[11]

Occupational health and safety centers on the protection of vulnerable groups in the workplace. Gender, age, risky employment and exposure to high-risk environments give rise to vulnerability. The epic contains narratives that provide a cultural lens on workplace ethics to mitigate risk in a hazardous work environment. Sita is abducted and put behind bars, violating ethical duty; however, her sacrifice can be viewed as her duty to protect vulnerable individuals. Sita's trial and suffering are analogous to harassment, discrimination, and unsafe environments in modern workplaces. The epic also underscores the shared duty to protect those who are at risk. Goldman and Sutherland state that Hanuman traces Sita in captivity. He prioritizes her safety and dignity, acting as a protector rather than an aggressor. His activities show that he has fulfilled an ethical commitment to safeguarding the weaker.[8]

After tracing Sita in captivity, Hanuman expresses his loyalty towards Rama. His act demonstrates that he has further upholds a moral obligation to protect the vulnerable from harm. Sattar and Din note that such acts exemplify leadership ethics rooted in dharma that safeguard the powerless as a moral obligation.[7] This is analogous to modern OHS frameworks where workers, supervisors and managers share collective responsibility for identifying risks and supporting vulnerable colleagues.[8] Vulnerable groups experience higher occupational injury and psychosocial stress. Walters and Wadsworth argue that marginalized workers often do not have the structural protections by which they are placed at greater risk of injury and exploitation.[12] WHO emphasizes that psychosocial risks—such as harassment, overwork and stress—are a growing threat to workers' wellbeing, particularly for vulnerable populations.[11] These findings warn that if we neglect duty toward the vulnerable, it will destabilize social and organizational harmony.

Weaving dharma into modern workplace ethics unfolds the twin obligation of leaders and institutions. It urges structural protections while promoting a culture that protects vulnerable individuals. Just as Rama and his allies become responsible for rescuing Sita from harm, organizations today should execute protective measures for all at risk. Ethical leadership, robust policies and participatory practices together uphold both safety and justice. Workplace safety culture depends on both leadership and the responsibility of workers. Goldman and Sutherland in Yuddha Kāṇḍa emphasize that Rama and his allies make a coordinated effort for the rescue of Sita. Their collective loyalty, shared duty and mutual trust make possible the successful rescue of Sita. Such activities prove that ethical outcomes arise from cooperative responsibility rather than individual action alone.[8] The epic champions this principle by showing the contribution of collective effort, loyalty and shared duty to overcome challenges. These lessons echo strongly with modern occupational safety frameworks that emphasize participatory responsibility.

Lakshmana serves Rama tirelessly during exile and battle. His unconditional support to Rama teaches a lesson on how the worker should be responsible, vigilant, and active for team safety. Brockington points out that the ideals of dharma in the epic are applicable to both rulers and subordinates. Their loyalty towards duty retains order.[5] In occupational contexts, this incident becomes helpful to understand how frontline workers play key role in implementing safety practices and monitoring risks. Goldman and Sutherland state that the construction of the Setu (bridge) to Lanka was accomplished because of the coordinated endeavor of the Vanara forces under guidance. Each contributes according to their capacity and exemplifies how shared responsibility and organized effort are essential for accomplishing high-risk tasks.[8] The mobilization of the Vanara Sena (monkey army) shows the importance of the value of teamwork in facing hazardous tasks such as the construction of the bridge. Sattar and Din emphasize that this episode demonstrates collective dharma in which every member contributes to a common mission

despite personal risk.[7] Employees' collective participation for hazard control helps to mitigate risk factors.

Workers' joint participation holds importance for effective safety systems. Walters and Wadsworth state that participatory arrangements significantly improve risk management and lead to better health and safety outcomes.[10] This imparts the lesson that collective commitment guarantees safety goals. Hanuman's courage and devotion in the Lanka mission exemplify how individual responsibility can inspire collective resilience. In safety psychology, Neal and Griffin demonstrate that workers' safety motivation and role perceptions directly predict safety compliance and participation.[13] These insights suggest that fostering solidarity and shared responsibility based on ethical duty bolsters workplace safety culture. Ethical decision-making in occupational health and safety requires balancing productivity, risk and human wellbeing. The epic presents multiple episodes where characters face dilemmas under conditions of danger, providing analogies for ethical decision-making in modern workplaces.

Rama decides to accept exile despite injustice. His acceptance shows that ethical duty (dharma) prevails over personal gain. Brockington explains that this choice reflects the prevalence of moral order over self-interest.[5] In OHS, leaders face dilemmas in which they cannot decide whether to suspend operations due to safety risks. Modern leaders can learn from Rama's adherence of ethical duty. Walters and Wadsworth show that workers' participation in safety decision-making ensures that risk management reflects both fairness and inclusivity.[11] This echoes the epic's lesson that justice requires shared responsibility in difficult choices. These insights suggest that ancient ethical models remain relevant in guiding modern occupational risk management. Knowledge transmission and training lay the foundation of sustainable occupational safety systems. The epic contains numerous episodes that focus on the transmission of knowledge and mentorship to ensure survival and ethical order. These lessons parallel modern safety training approaches. Information-sharing and cultural reinforcement are critical for building robust organizations. Bandura's social learning theory explains that individuals acquire behaviors through observation and practice. This theory highlights the importance of mentorship in shaping safe practices.[14] Burke et al. further assert that effective safety training programs significantly widen worker knowledge, behavior and injury prevention outcomes. Training enhances the role of structured learning in occupational safety systems.[15]

Rama guides Lakshmana during their exile, and Lakshmana learns about safety and discipline. Then Lakshmana develops skill to recognize the importance of dharma. Brockington notes that dharma in the Ramayana goes beyond personal duty, focusing on principles transmitted through dialogue and example. Such a principle ensures continuity across generations.[5] In OHS, this resembles training models in which senior workers train younger employees. They bolster safe practices through both instruction and example. Hanuman can leap to Lanka because he knows his strengths. His discipline and skills further make him bold to earn success. The epic itself serves as a historical cultural training text, transmitting ethics and duty through storytelling. In organizational contexts, cultural narratives and safety stories serve a similar role. In workplaces, effective safety training systems are required to institutionalize knowledge transfer. Walters and Wadsworth highlight that workers' participation in safety training enhances trust and compliance.[11] These insights mirror Ramayana's narrative method that reinforces repeated storytelling for the protection of values, responsibility, and ethical conduct across generations. Crisis management and recovery play an important role in occupational safety. Their importance is evident in industries where disasters and emergencies are inevitable. The epic depicts a crisis resulting from abduction and exile to war. It also provides models of resilience, planning and recovery. These cases parallel contemporary occupational health and safety practices. Ravana's abduction of Sita unsettles the social and moral order. However, Sita's crisis is addressed and managed based on the principle of dharma. Modern organizations should learn lessons from Sita's process of crisis management to mitigate workplace disaster such as accidents, industrial failures and pandemics. They should mobilize resources to protect workers. Hanuman's reconnaissance mission to Lanka exhibits his rapid response through agility and courage. Goldman and Sutherland assert that Hanuman balances courage with restraint, gathers critical information, and minimizes unnecessary harm. His activities demonstrate his strategic and ethical crisis response.[8] Rasmussen highlights that risk management in complex systems requires adaptive and proactive strategies, reinforcing the need for flexibility and situational awareness in crisis conditions.[16] After Ravana's defeat, Rama restores Sita and the kingdom. His role champions

recovery and return to normalcy. In safety science, recovery refers to the restoration of systems and ensures psychosocial wellbeing and learning from crisis to prevent recurrence. Dekker argues that resilient organizations adopt a just culture that supports learning from failure while maintaining accountability.[17] These frameworks echo the Ramayana's narrative of renewal after turmoil.

Occupational health and safety center prevention frameworks. Such frameworks can save lives and resources if a timely forecast about probable hazardous cases is undertaken before their manifestation. The epic includes preventive measures such as boundaries, warnings and foresight. Such measures parallel with proactive safety strategies today. The episode of the Lakshmana Rekha—the protective boundary drawn to shield Sita from harm—symbolizes preventive safety measures. Goldman and Sutherland in the Araṇya Kāṇḍa assert that Lakshmana gives a warning to Sita to be cautious of the probable harm from enemies. His warning emphasizes the importance of remaining within a safeguarded boundary to avoid unseen danger, thereby illustrating the preventive function of rules and caution.[8] Sita crosses the boundary, and thus her abduction takes place. The narrative delivers the message that boundaries and rules are designed to prevent exposure to hazards. Hopkins notes that effective safety measures require foresight, with leading indicators that identify vulnerabilities before disasters occur.[18] The Ramayana's emphasis on caution, preparedness and adherence to rules parallels these preventive frameworks. These findings suggest that preventive measures succeed when leaders actively model and enforce safety values, just as Rama upholds dharma in guiding his followers.

Occupational health and safety systems should adopt ethical principles to address the problems of workers in the workplace. The Ramayana's concept of dharma provides universal ethical dimensions. Spiritual ethical dimensions can be substantial to improve contemporary frameworks such as ILO conventions, ISO standards, and WHO guidelines. Brockington argues that dharma's universal dimension propagates across personal, social and institutional levels.[5] Goldman and Sutherland in the Ayodhya Kanda mention that Rama possesses a leadership attribute. His leadership qualities treat the protection of subjects and the maintenance of moral order as inseparable duties. His ethical responsibility goes beyond personal conduct to institutional obligation.[8] In workplace safety, this suggests that ethical duty to protect life transcends legal compliance, extending to all actors in the system. The ILO's 2023 Declaration on Fundamental Principles emphasizes safe and healthy working conditions as a fundamental right.[19] This aligns with dharma's mandate to protect life and ensure justice. Just as Rama and his allies bear responsibility for collective wellbeing, employers and governments are ethically obligated to safeguard workers. ISO 45001:2018 outlines leadership, worker participation and continuous improvement as foundations of OHS management systems.[20] Similarly, WHO and ILO emphasize psychosocial protections alongside physical safety.[14,15] Sattar and Din argue that leadership ethics from Indian epics reinforce these priorities by embedding fairness, protection, and justice as non-negotiable duties.[7] Integrating dharma into these standards highlights the moral responsibility underpinning technical frameworks. The Vision Zero approach emphasizes preventing all injuries and promoting holistic well-being. Zwetsloot et al. argue that moving from prevention to proactive wellbeing requires cultural transformation.[21] Embedding dharma into Vision Zero frameworks ensures that safety culture rests not only on risk management but on moral responsibility, justice, and care for all workers.

Conclusion

Occupational health and safety should integrate both technical and ethical principles to make the workplace atmosphere more soothing and comfortable. The modern occupational frameworks provide scientific and procedural foundations; however, they lack cultural values and commitments. Therefore, they must embrace ethical values and norms to develop holistic approaches for the betterment of the workers. The Ramayana's concept of dharma complements modern frameworks through its ethical principles. They can only bolster occupational safety culture by promoting duty, fairness, justice, and collective responsibility. By analyzing episodes of leadership, vulnerability, teamwork, crisis, and prevention, this study concludes that the Ramayana's ethical insights can contribute to mitigating contemporary occupational safety challenges. Modern occupational safety mechanisms become complete after the integration of Rama's integrity, Sita's notion of the protection of the vulnerable, Lakshmana's and Hanuman's collective responsibility and resilience and the preventive safety mechanism of Lakshmana Rekha. These narratives provide

cultural metaphors that enrich modern safety discourse. Integrating dharma into occupational safety culture ensures that safety stems from a moral obligation to respect human dignity. By bridging ancient ethical wisdom with global safety standards, organizations can cultivate more just, resilient, humane and safer workplaces.

References

1. Rao VN. Dharma and ethics in the Ramayana. J Indian Philos. 2017;45(2):243-60.
2. Guldenmund FW. The nature of safety culture: a review of theory and research. Saf Sci. 2000;34(1–3):215–57.Available from: https://doi.org/10.1016/S0925-7535(00)00014-X
3. World Health Organizati12eon. Occupational health: a manual for primary health care workers. Cairo: WHO Regional Office for the Eastern Mediterranean; 2002. Available from: https://iris.who.int/items/929d9baa-6ea1-4403-aa37-5dcdacb59f28
4. International Labour Organization. Guidelines on occupational safety and health management systems (ILO-OSH 2001). Geneva: ILO; 2001. Available from: https://www.ilo.org/publications/guidelines-occupational-safety-and-health-management-systems-ilo-osh-2001
5. Brockington J. The concept of "Dharma" in the Rāmāyaṇa. J Indian Philos. 2004;32(5–6):655–70. Available from: https://link.springer.com/article/10.1007/s10781-004-8639-0
6. Bisbey TM, Kilcullen MP, Thomas EJ, Ottosen MJ, Tsao K, Salas E. Safety culture: an integration of existing models and a framework for understanding its development. Hum Factors. 2021;63(1):88–110. Available from: https://doi.org/10.1177/0018720819868878
7. Sattar Z, Din I. Dharma and leadership ethics in Indian epics: implications for modern management. J Hum Values. 2020;26(3):223–34.
8. Goldman RP, Sutherland SJ, Goldman AJ, van Nooten B, trans. The Ramayana of Valmiki: an epic of ancient India. Princeton (NJ): Princeton University Press; 1984–2009. Available from: https://press.princeton.edu/books/paperback/9780691173986/the-ramayana-of-valmiki-an-epic-of-ancient-india-volume-vi?srsltid=AfmBOoolai8oDvgjkhLsGIBoOIeV1sGgXUEyD28co7yS7W1rfhhUaEbX
9. Clarke S. An integrative model of safety climate: Linking psychological climate and work attitudes to individual safety outcomes using meta-analysis. J Occup Organ Psychol. 2010;83(3):553–78. Available from: https://doi.org/10.1348/096317909X452122
10. Zohar D. Safety climate in industrial organizations: theoretical and applied implications. J Appl Psychol. 1980;65(1):96–102. Available from: https://psycnet.apa.org/doi/10.1037/0021-9010.65.1.96
11. Kelloway EK, Mullen J, Francis L. Divergent effects of transformational and passive leadership on employee safety. J Occup Health Psychol. 2006;11(1):76–86. Available from: https://psycnet.apa.org/doi/10.1037/1076-8998.11.1.76
12. Walters D, Wadsworth E. Worker participation in the management of occupational safety and health: Qualitative evidence from ESENER-2. European Agency for Safety and Health at Work (EU-OSHA). 2016. Available from: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://vzd.mddsz.gov.si/document-download/worker-participation-in-the-management-of-occupational-safety-and-health-qualitative-evidence-from-esener-2-2022-01-14-105
13. Neal A, Griffin MA. Safety climate and safety behaviour. Aust J Manag. 2002;27(1_suppl):67–75. Available from: https://doi.org/10.1177/031289620202701S08
14. Bandura A. Social learning theory. Englewood Cliffs: Prentice Hall. 1977. Available from: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.asecib.ase.ro/mps/Bandura_SocialLearningTheory.pdf
15. Burke MJ, Sarpy SA, Smith-Crowe K, Chan-Serafin S, Salvador RO, Islam G. Relative effectiveness of worker safety and health training methods. Am J Public Health. 2006;96(2):315–24. Available from: https://doi.org/10.2105/AJPH.2004.059840
16. Rasmussen J. Risk management in a dynamic society: a modelling problem. Saf Sci. 1997;27(2–3):183–213. Available from: https://doi.org/10.1016/S0925-7535(97)00052-0
17. Dekker S. Just culture: balancing safety and accountability. 2nd ed. Boca Raton: CRC Press. 2012. Available from: https://doi.org/10.4324/9781315251271

18. Hopkins A. Thinking about process safety indicators. Saf Sci. 2009;47(4):460–65. Available from: https://doi.org/10.1016/j.ssci.2007.12.006
19. International Labour Organization. Safety and Health at Work: A Vision for Sustainable Prevention. Geneva: ILO. 2013. Available from: https://www.ilo.org/global/topics/safety-and-health-at-work/lang--en/index.htm
20. International Organization for Standardization. ISO 45001:2018 Occupational health and safety management systems – Requirements with guidance for use. Geneva: ISO. 2018. Available from: https://www.iso.org/standard/63787.html
21. Zwetsloot GIJM, Leka S, Kines P. Vision zero: From accident prevention to the promotion of health, safety and well-being at work. Policy and practice in health and safety. 2017;15(2):88-100. Available from: https://doi.org/10.1080/14773996.2017.1308701

International Journal of Occupational Safety and Health

ISSN: 2091-0878 (Online) ISSN: 2738-9707 (Print)

Case Study

Breaking ground and breaching safety: a case study of construction health hazards

Suganya Bharathi S[1], Celina A[2]

[1]Assistant Professor, School of Law, SRM Institute of Science and Technology, Kattankulathur, Chengalpattu District, Tamil Nadu, India, [2]Associate Professor, Faculty of Management, SRM Institute of Science and Technology, Kattankulathur, Chengalpattu District, Tamil Nadu, India

Corresponding author:
Suganya Bharathi S,
Assistant Professor, School of Law, SRM Institute of Science and Technology, Kattankulathur, Chengalpattu District, Tamil Nadu, India
E-mail: suganyas6@srmist.edu.in
ORCID ID: https://orcid.org/0000-0003-2715-2357

Date of submission: 27.02.2025
Date of acceptance: 03.04.2026
Date of publication: 15.04.2026
Conflicts of interest: None
Supporting agencies: None
DOI:https://doi.org/10.3126/ijosh.v16i1.76101

Copyright: This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License

ABSTRACT

Introduction: India's construction industry constitutes 16.4% of worldwide occupational dangers, although employing just 7.5% of the labor force, indicating significant safety shortcomings. Contributing elements encompass ineffective communication, absence of protective equipment, hazardous work practices, insufficient training, psychological strain, deficient safety culture, and restricted legal adherence. Notwithstanding the sector's multidisciplinary characteristics necessitating robust safety planning, insufficient protections persistently result in significant accidents and productivity declines.

Methods: This study investigates methods to improve safety performance utilizing Building Information Modeling (BIM) for proactive risk detection and real-time monitoring, alongside Blockchain for transparent and tamper-proof compliance administration.

Results: Blockchain guarantees secure compliance records, while BIM facilitates early hazard detection, improved risk visualization, and coordination. Together, these features improve accountability, lower accident rates, and increase overall construction safety.

Conclusion: By enabling proactive risk management and transparent compliance, lowering accidents, increasing productivity, and directing stakeholders toward successful digital adoption, the integration of BIM and Blockchain enhances construction safety.

Keywords: Building information modeling (BIM), blockchain, construction accidents

Introduction

The construction sector in India is experiencing rapid growth due to extensive infrastructure renovation, gentrification, and government programs such as the Smart Cities Mission and the Pradhan Mantri Awas Yojana (PMAY). With the sector's expansion, the necessity for rigorous safety measures has grown more pressing. Construction sites generally entail heavy machinery, intricate coordination, and a substantial, varied crew, factors that inherently increase the likelihood of accidents. Given that the construction sector is among India's greatest employers, enhancing safety protocols is both a legal obligation and a moral need.

Notwithstanding considerable modernization, the business persists in documenting a

substantial number of incidents annually, many of which lead to grave injuries or fatalities. The National Crime Records Bureau (NCRB) reports that construction is among India's most hazardous professions, with occurrences often attributed to insufficient training, lack of awareness, and negligence of safety regulations. Construction safety concerns are prevalent worldwide; yet Indian construction workers are among the most susceptible labor groups internationally. Due to the business's labor-intensive nature, safety must be addressed extensively at the national level.

Approximately 10 million individuals are directly working in construction, seeing four to five times more fatal events than their counterparts in industry. The Construction Industry Development Council (CIDC) reports that 165 per 1,000 workers have job-related injuries, with several individuals exposed to hazardous chemicals that may lead to silicosis, asbestosis, lead poisoning, and other occupational illnesses. The extensive unregulated construction workforce comprises more than 44 million people.[1] Despite constituting about 7.5% of the worldwide workforce, they comprise 16.4% of global occupational dangers. Research demonstrates that 62.8% of accidents occur on small construction sites, compared with 47.4% on larger projects,[2] highlighting disparities in safety standards and inadequate compliance with occupational health regulations. A significant portion of this data is underreported, obscuring the actual magnitude of the issue.[3]

The construction sector in India has a fatal accident frequency rate (FAFR) of 15.8 events per 1,000 workers yearly, about fifty times more than that of the United States. The International Labor Organization (ILO) indicates that the probability of both fatal and non-fatal accidents in India is 2.5 times higher than in North America or Europe.[3] These figures indicate that India's safety standards are much inferior to international norms.

The continuous underreporting of occurrences significantly contributes to India's worrying accident rates. The ILO underscores the necessity of reporting and investigating accidents and occupational illnesses to identify risks and enact remedial actions. Nevertheless, in India, reporting remains unreliable.[4] Numerous employees refrain from seeking medical attention or informing employers about injuries.[4,5] Limited employee understanding, lack of support systems, employment instability, and fear of retribution inhibit reporting. Wider societal issues, such as feeble trade unions, language and caste disparities, socioeconomic inequities, governance deficiencies, and liberalized labor regulations, further obstruct transparent reporting.[6]

The construction labor is predominantly temporary, constantly relocating between sites. This engenders extremely volatile and intricate working conditions. This research investigates the many impediments to worker safety and health in the Indian construction sector and provides effective strategies to enhance safety performance.[7]

Table 1: Case Report on Occupational Safety in India's Construction Sector

Accident	Date	Place	Cause of the accident	Source
A tragic incident occurred at a construction site where nine workers lost their lives after a portion of the soil caved in.	Oct 12, 2024	Gujarat, Mehsana district	No safety Protocols	9 killed after soil caves in at construction site in Gujarat, PM condoles | India News - Business Standard
A ceiling fall at a Peenya building site claimed the lives of two workmen.	August 10, 2024	Peenya, Bengaluru	Safety Concerns:	The Hindu reports that two workmen were killed when a

			Failure to follow safety procedures at the building site	ceiling collapsed at a Peenya building site.
(i) A worker died after falling from the twentieth story of a building that was still under construction. (ii) A worker was killed when a cargo lift crashed from the 17th floor (iii) At a Bhiwandi site, a lift collapsed, killing two workers (iv) In Kandivali, a lift crashed, causing two workers to fall from the 24th floor	September 3. 2023 June 15, 2023 November 22, 2022 August 27, 2020	Byculla (Mumbai) Kurla (Mumbai) Bhiwandi (Thane district) Kandivali (Mumbai)	Safety concerns: Lift and safety device certification and monitoring are handled by third-party companies rather than government organizations. It is noted that there is a shortage of technological know-how in monitoring safety measures.	Construction worker fatalities in Maharashtra have tripled in three years | Mumbai News - Times of India
This 28-year-old construction worker died when he stumbled and tumbled from a height of around 7.5 meters.	August 27, 2022	Pune	Failed to implement safety precautions such as setting up security netting and failing to give workers safety belts or helmets.	India's construction industry is perilous | British Safety Council India
Gujarat saw 69 fatalities in 2014, 62 in 2015, 55 in 2016, 67 in 2017, and 137 fatal accidents in 2018.	May 12, 2019	Gujarat	Safety Concerns	India has 80% "unsafe" building sites and 20 times more fatalities than Britain.
According to 2016 research administered by IIT Delhi and the National Institute of Technology Surat, construction accounts for at least 11,614 of the approximately 48,000 deaths that occur in workplace accidents in India each year.	2016	India	Unsafe work practice	Indian construction is a precarious industry - British Safety Council India

Root Causes of Construction Mishaps: Identified from the real incidents

Construction accidents frequently result from a confluence of systemic, technical, and operational deficiencies. A primary factor is the use of inferior materials, often chosen to save costs. These materials compromise structural integrity and may fail to endure environmental stresses or load demands, resulting in fractures, erosion, or even collapse. This endangers public safety and incurs costly repairs, legal ramifications, and a deterioration of confidence.

A crucial element is the noncompliance with safety requirements. Disregarding critical protocols, such as using safety harnesses, securing sturdy scaffolding, or providing sufficient protective equipment, significantly heightens the risk of falls, equipment malfunctions, and accidents. Disregarding technical norms during construction or

maintenance jeopardizes both worker safety and structural integrity.

Insufficient inspections and oversight also lead to incidents. When regulatory authorities or project overseers fail to conduct timely audits, hidden flaws go undetected. Such oversights might develop into significant structural issues that become apparent only after extensive harm has transpired.

Moreover, unrealistic timelines and financial constraints compel contractors to resort to shortcuts. Neglecting quality materials, minimizing competent personnel, or hastening processes may seem cost-effective but can lead to long-term safety risks and maintenance difficulties.

Unsafe Work Practices and Procedures- Causes:

The literature critique provides an overview of the numerous problems and difficulties related to workplace safety among Indian construction workers. Each of these concerns is covered in this section:

(i) Workplace Ergonomics

Injuries and illnesses in the construction sector can arise from inadequate postures, confined areas, elevated noise levels, vibrating equipment, severe temperatures,[8] and disorganized work.[9] These circumstances elevate physical stress and the probability of mistakes. Ergonomic redesign, enhancing work postures, task flow, and workplace configuration, can markedly increase comfort, diminish tiredness, and elevate safety.[10]

(ii) Enhancing On-Site Communication in Construction

The efficient dissemination of information continues to pose a significant issue on building sites. Information overload, delays, and inadequate communication with subordinate personnel foster hazardous workplaces.[11] Indian sites frequently rely significantly on manual oversight, and activities are seldom recorded systematically. The absence of record-keeping hinders the tracking of job progress, risk assessment, and timely communication, hence undermining site coordination and safety.

(iii) Psychosocial Dynamics and Their Effects

Safety is affected by both physical circumstances and mental and cultural variables. Stress, weariness, anxiety, and burnout strongly influence employee behavior and performance,[12] a conclusion corroborated by international research.[13] Extended hours, restricted social interaction, adverse weather conditions, and rigorous scheduling exacerbate stress levels among employees and supervisors.[14] Indian construction projects frequently entail stringent timelines, constant vigilance, and task-related pressure, leading to psychological stress, interpersonal discord, and diminished general well-being.

(iv) Workplace Safety: Orientation and Behavioral Modification

Insufficient safety knowledge and careless attitudes towards dangers continue to prevail at several locations.[15] Industrial safety ethics encompass collective convictions, competencies, and actions that mitigate risks. Establishing a robust safety climate characterized by clearly stated, practiced, and enforced regulations is crucial for enhancing compliance and mitigating accidents.

(v) Regulations Influencing Occupational Health and Safety Practices

Despite regulations such as the Occupational Safety, Health, and Working Conditions Code (2020) and prior legislation that provide safeguards, some workers in the unorganized sector remain unprotected.[16] Enforcement deficiencies and implementation obstacles within the fragmented construction sector diminish the efficacy of these policies.[17,18]

Solutions for Minimizing Construction Mishaps: Lessons from the Field

(i) Awareness Building and Capacity Development

Important elements influencing safety at Indian building sites include knowledge of potential

risks, the degree of risk posed by those risks, and the tools, equipment, and procedures available to mitigate them. Employees in the building industry sector frequently have low levels of education and are inexperienced, unskilled, and untrained. The likelihood and type of danger associated with the tasks these employees perform must be explained to them, and safety training programs must be implemented. When it comes to raising employees' awareness of the need to adhere to workplace safety regulations, management plays a crucial role.[19]

(ii) BIM as a Catalyst for Safer Construction Environments

One of the most neglected topics in the building sector has always been safety. Inadequate site safety leads to mishaps that cause both monetary and personal losses. Present-day security procedures are inadequate to oversee on-site safety, as detailed above. Automation is advancing rapidly and has several applications in construction safety. The Creation of a BIM-based automated safety checker model makes it clear that BIM is used for automated scaffolding,[20,21] risk identification, and fall hazard identification.[22] Furthermore, because of their many unique characteristics and capabilities, BIM and Geographic Information System (GIS) integration are powerful platforms that are often utilized in the construction sector.[23] It facilitates the creation of safe construction zones,[24] and the digital representation of the actual environment by integrating BIM and GIS data.[23] Particularly when it comes to India, virtually little BIM has been used for safety. There isn't much research on BIM for framework systems,[25] BIM and GIS integration for site safety,[26] or BIM for site layout planning.[27] This section of the survey has been added to raise awareness of the potential applications of BIM for safety. It includes the safety benefits of BIM. The use of BIM might improve current procedures and highlight important issues with project time and expense overruns. Construction productivity has increased significantly in countries with BIM mandates, including the USA, the UK, France, Germany, and Singapore. If the anticipated long-term benefits are to be achieved, navigating India's lack of a BIM mandate in the near future will be a significant challenge. This section presents the opinions of construction experts on the BIM mandate, the steps required to comply with it, and BIM's future potential.

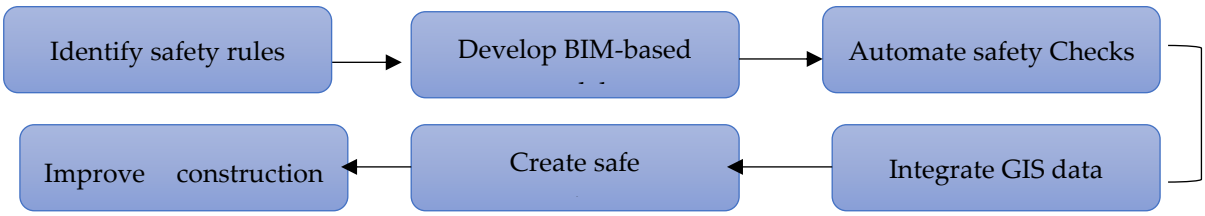


Figure 1: Integrating BIM for Enhanced Construction Safety

Table 2: How BIM Optimizes Safety Strategies in Construction

SI. No	Advantages of a Safety-First Approach
1.	Administration of a site's layout
2.	Modeling and picturing construction risks and precautions
3.	Prompt handling of potentially dangerous tools and supplies
4.	Swift and productive decision-making
5.	On-the-spot safety oversight and management
6.	Safety knowledge and instruction
7.	Appraisal of safety
8.	Risk-prone locations are identified for future use.
9.	Offering and notifying the employees of mitigation strategies
10.	Quantity take-off for required safety gear
11.	When required, issuing safety warnings to employees on the job site
12.	An automated method for verifying safety norms and requirements

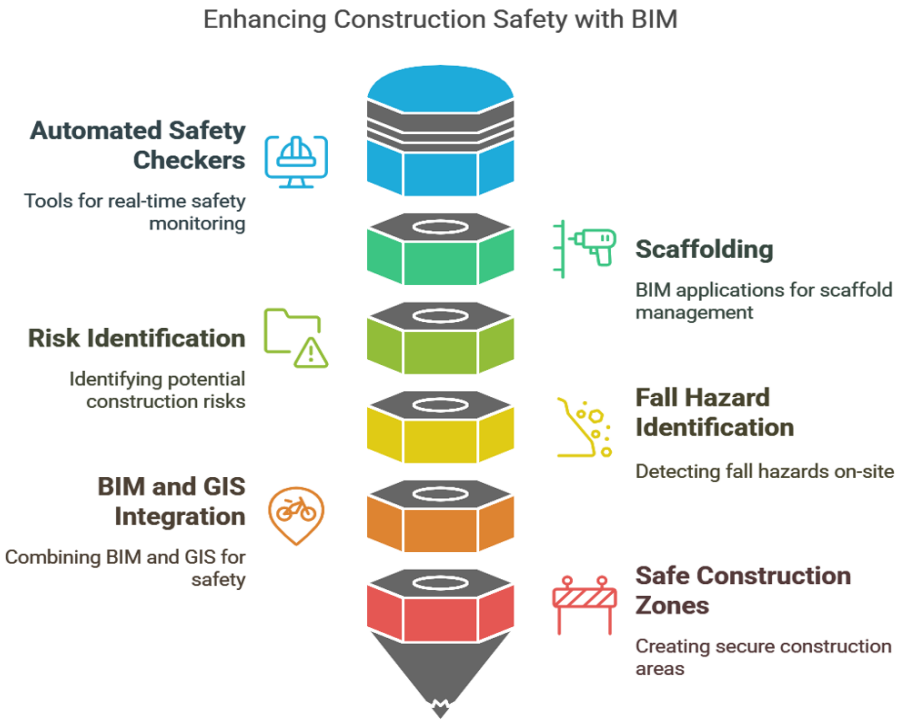


Figure 2: Safety enhancement with BIM

Automated safety inspections and AI-Driven risk evaluations facilitate danger identification, while IoT sensors and drones provide real-time monitoring of site conditions. Augmented Reality (AR) and Virtual Reality (VR) simulations offer immersive safety training for employees. BIM guarantees regulatory compliance through automated reporting and blockchain integration for secure safety documentation. Following construction, BIM facilitates facility management by forecasting maintenance requirements and enhancing emergency response strategies. Through the integration of intelligent monitoring, predictive analytics, and automation, BIM markedly reduces construction hazards, thereby fostering a safer, more efficient, and more regulation-compliant work environment. Their use is essential for contemporary, safety-oriented building methodologies.

(iii) Leveraging Blockchain for Enhanced Risk Management and Compliance

Applying blockchain technology in risk management has exciting prospects.[28] For instance, look at the application of blockchain

technology to compliance checks in the building sector. They suggested using asset tracking and blockchain technology in tandem to address problems such as disputes, costly operations, and transparency issues. An enduring transaction record and semi-automated compliance tracking resulted from the structure of linked apps and an operational workflow they built. Similarly, while ensuring adherence to technical norms and standards, the SSI-based system facilitates the development of digitization processes.[29] Construction project risk management is also relevant to the POSH dissemination structure, which was previously covered in the context of record administration and preservation.[30] It specifically acts to strike a balance between privacy concerns and threats to workplace safety and health.

[31] emphasized the potential of blockchain technology to improve on-site assembly inspection in modular construction, particularly during the COVID-19 pandemic, when remote and precise safety verification was crucial. Their prototype solution employed blockchain's consensus process to enable project participants to authenticate module information, therefore assuring data correctness, transparency, and accountability in safety compliance. Likewise, illustrated blockchain's efficacy in enhancing equipment safety management, decision-making, accident monitoring, and supervision.[32]

Blockchain is increasingly recognized as an essential instrument in building quality control, a crucial aspect of risk management.[32] It proposed the "Product Organization Process (POP) Quality Chain," a blockchain-based system that incorporates smart contracts, consensus mechanisms, and POP-model clustering to oversee and verify construction quality data. [33] demonstrated that blockchain establishes an immutable, decentralized record for the quality of items and processes. Recent findings demonstrate that experimental blockchain systems can improve the accuracy of information exchange during onsite modular assembly, thereby enhancing quality and risk management.

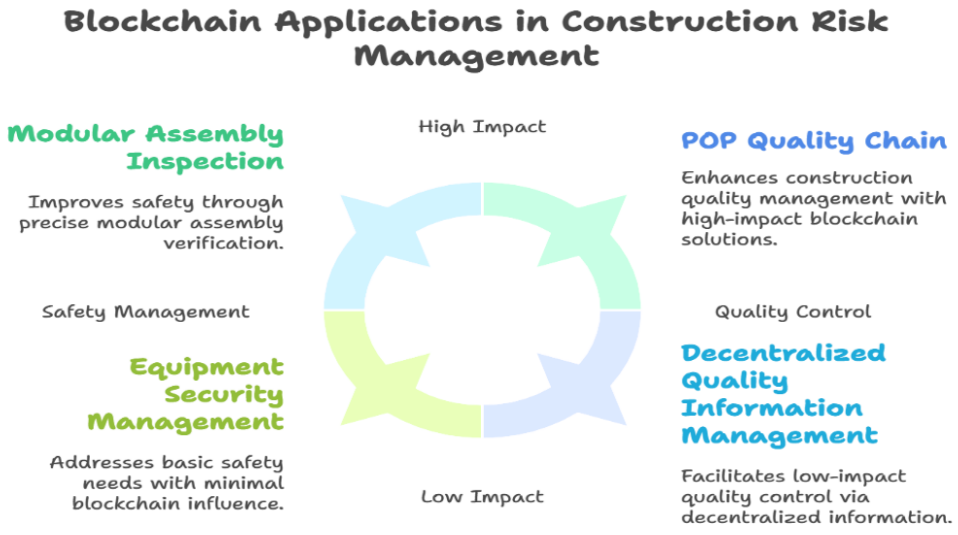


Figure 3: Blockchain applications in mitigating safety risks

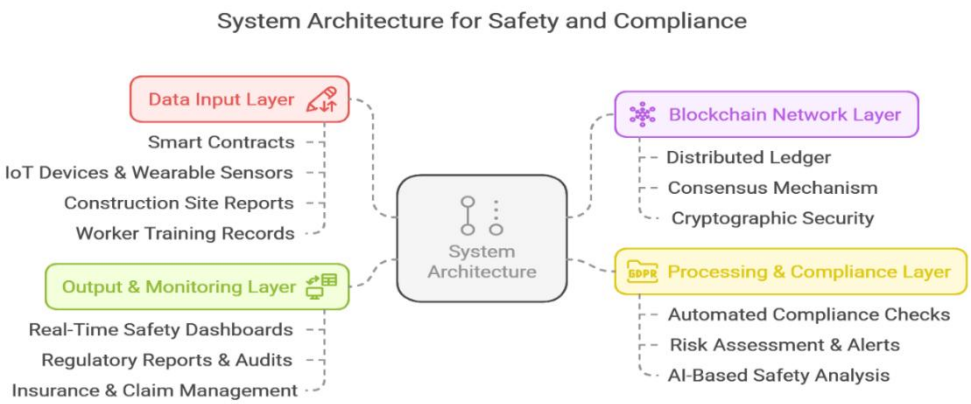


Figure 4: Blockchain architecture for safety compliance

Blockchain improves risk management and compliance in construction by providing secure, transparent, and automated procedures. IoT sensors, drones, and on-site inspections collect real-time data regarding safety compliance, material quality, and worker adherence to laws. Aggregated data is stored on a decentralized ledger, ensuring immutability and tamper-resistant records through blockchain integration. Smart contracts automate compliance checks, triggering notifications for infractions. Blockchain facilitates real-time safety monitoring, enabling regulatory authorities to remotely oversee building-site operations, thereby reducing the need for manual inspections. All stakeholders, contractors, regulatory bodies, and project managers have access to the encrypted safety record to ensure responsibility and mitigate fraud. AI-driven analytics on blockchain can forecast potential threats, facilitate proactive decision-making, and minimize mishaps. This application bolsters confidence, enforces compliance, and mitigates construction hazards, thereby enhancing overall project safety and efficiency.

Discussion

The Indian construction sector continues to face significant safety issues due to the use of substandard materials, inadequate worker training, unrealistic timelines, and widespread noncompliance with safety rules.[34,35] Resolving these difficulties requires a comprehensive strategy that integrates technological advancement, strengthened laws, and cultural transformation. This section outlines effective techniques to mitigate accidents and enhance safety performance at construction sites.

To ensure structural integrity, it is imperative that only superior materials be used. A compulsory third-party quality audit can authenticate products before utilization, bolstered by a nationwide register of accredited suppliers.[36] Integrating this register into governmental and corporate procurement processes can help prevent the introduction of substandard materials into projects. Companies that violate material requirements should incur severe consequences, such as fines or blacklisting, to discourage harmful behavior.[37]

Safety compliance must be enhanced by technology-driven monitoring. IoT devices and wearable sensors can monitor employee mobility, identify hazardous circumstances, and deliver instantaneous notifications to supervisors.[38,39] Financial sanctions and interim closures for non-compliance can enhance accountability. A consolidated repository of site-specific safety information would facilitate the identification of recurrent violators and bolster data-driven enforcement efforts.[40]

Efficient oversight and examination are essential for accident prevention. Drones and AI-driven inspection tools may detect structural anomalies, risky practices, and hazardous areas in real time.[41] Significant building initiatives must be subject to periodic evaluations performed by

independent safety organizations. These audits must assess equipment conditions, evaluate worker safety procedures, and ensure compliance with guidelines. Transparent disclosure of audit results can promote accountability and ongoing enhancement.[42]

Impractical timetables frequently compel contractors to expedite tasks, jeopardizing safety [43]. Advanced project management systems like Primavera and Microsoft Project facilitate the development of viable schedules that incorporate safety standards, cost, and time factors [44]. Collaborative planning, including customers, contractors, engineers, and labor unions, ensures that safety is prioritized over expediency or financial constraints.

Mitigating the deficiency of a proficient workforce is vital. Collaborations with technical institutes can facilitate accredited training programs encompassing equipment operation, emergency response, and safety principles.[40] AR and VR training simulations help equip workers for real-world situations by familiarizing them with virtual threats and appropriate reaction strategies.[45]

Suboptimal ergonomics is a primary contributor to occupational injuries. Ergonomically constructed tools, adaptable scaffolding, and lightweight equipment may alleviate physical strain and enhance efficiency.[46] Educating employees on safe posture, appropriate tool use, and manual handling techniques will further reduce musculoskeletal injuries.

Effective communication is essential for coordination and accident prevention. Wearable gadgets, such as smart helmets with integrated speakers and microphones, can improve communication, especially in emergencies [47]. Multilingual training resources facilitate accommodating linguistic diversity among employees, whilst centralized communication tools enable supervisors to oversee workflows and proactively detect risks.

Psychosocial factors such as stress, weariness, and interpersonal conflict substantially impact safety behavior.[48] Implementing on-site counseling, stress-relief initiatives, and rewards for safe behaviors can enhance morale and promote adherence. Identifying "safety champions" strengthens a culture of responsibility and vigilance.

Sustained safety enhancement necessitates behavioral modification. Consistent safety orientations and refresher courses facilitate the internalization of safe practices among workers. Designating qualified safety ambassadors on-site can facilitate peer learning and strengthen compliance with safety regulations. Ultimately, regulatory adjustments are essential. Implementing a standardized national safety code, periodically revised to incorporate technological and industrial advancements, can reduce uncertainty.[49] Consistent training for site managers guarantees adherence to changing rules.

Technological innovations such as Building Information Modeling (BIM), wearable sensors, and automated machinery may enhance safety by forecasting threats, monitoring worker health, and minimizing human error. Public-private collaborations may facilitate awareness campaigns, research, and training activities, while incentives such as tax advantages can motivate firms to prioritize safety. Implementing these measures can substantially reduce construction accidents in India, leading to safer work sites, increased productivity, and a stronger industry reputation.

Conclusion

The construction sector in India experiences a fatal accident frequency rate (FAFR) of 15.8 per 1,000 workers yearly, about 50 times more than that of the United States. The International Labor Organization (ILO) reports that the probability of both fatal and non-fatal accidents in India is 2.5 times higher than in North America or Europe, reflecting much worse safety standards.

A key contributor to these elevated accident rates is chronic underreporting. The ILO emphasizes

that accurate reporting and investigation of workplace accidents are crucial for risk identification; nevertheless, India's reporting is inconsistent. A multitude of employees refrain from reporting accidents owing to insufficient awareness, inadequate assistance, job uncertainty, and apprehension regarding company punishment. Wider social issues, such as weak trade unions, linguistic and caste barriers, economic inequalities, governance deficiencies, and lax labor laws, further hinder truthful reporting.

This study seeks to analyze these obstacles and provide methods to enhance safety performance in India's construction sector.

Funding

There is no outside funding for this research.

Conflict of Interest

There is no conflict of interest for the researchers regarding this article's research, authorship, and /or publishing.

References

1. Kalyani M. Unorganised workers: a core strength of Indian labour force: an analysis. Int. J. Res. Business Stud. Manag. 2015;2(12):44–56. Available from: https://www.semanticscholar.org/paper/Unorganised-Workers%3A-A-Core-Strength-of-Indian-An-Kalyani/a7804be32aa4e9780d18e9f9f7dd0ba38030a02d
2. Kanchana S, Sivaprakash P, Joseph S. Studies on labour safety in construction sites. Sci. World J. 2015;1:590810. Available from: https://doi.org/10.1155/2015/590810
3. Patel DA. Estimating The Number of Fatal Accidents and Investigating the Determinants Of Safety Performance in Indian Construction. Indian Institute of Technology Delhi. 2015a. Available from: Microsoft Word - 2016 ARCOM Full Proceedings - Vol 1 Final
4. Taylor Moore J, Cigularov KP, Sampson JM, Rosecrance JC, Chen PY. Construction workers' reasons for not reporting work-related injuries: An exploratory study. International Journal of Occupational Safety and Ergonomics: JOSE. 2013;19(1):97–105. Available from: https://doi.org/10.1080/10803548.2013.11076969
5. Rosecrance JC, Cook TM, Anton DC, Merlino LA. Carpal tunnel syndrome among apprentice construction workers. American Journal of Industrial Medicine. 2002;42(2):107–16. Available from: https://doi.org/10.1002/ajim.10093
6. Díaz JÁ, Comhaire G, Pisker L, Sabin N, Ticona SA, Gibon C, et al. The silent death of workers in India [Internet]. Equal Times. [cited 2026 May 1]. Available from: https://www.equaltimes.org/the-silent-death-of-workers-in?lang=en
7. Samanta S, Gochhayat J. Critique on occupational safety and health in construction sector: An Indian perspective. Materials Today: Proceedings. 2023;80:3016–21. Available from: https://doi.org/10.1016/j.matpr.2021.05.707
8. Gangopadhyay S, Das B, Das T, Ghoshal G, Ghosh T. An ergonomics study on posture-related discomfort and occupational-related disorders among stonecutters of West Bengal, India. International Journal of Occupational Safety and Ergonomics: JOSE. 2010;16(1):69–79. Available from: https://doi.org/10.1080/10803548.2010.11076830
9. Ray PK, Parida R, Saha E. Status survey of occupational risk factors of manual material handling tasks at a construction site in India. Procedia Manufacturing. 2015;3:6579–86. Available from: https://doi.org/10.1016/j.promfg.2015.07.279
10. Drisya S, Das BB, Parida R. Ergonomic Design of Products and Worksystems - 21st Century Perspectives of Asia. Managing the Asian Century (P Ray & J Maiti Eds). Springer. 2018. Available from: https://doi.org/10.1007/978-981-10-5457-0
11. Khan A, Prem H, Pai S. Challenges in implementation of safety practices for building implosion technique in India. In Advances in Intelligent Systems and Computing. Springer Singapore. 2020;457–65. Available from: https://doi.org/10.1007/978-981-15-0936-0_49
12. Panneer S. Health and safety of women workers in informal sector: Evidences from construction and beedi rolling works in India. In Health, Safety and

Well-Being of Workers in the Informal Sector in India. Springer Singapore. 2019;61–75. Available from: https://doi.org/10.1007/978-981-13-8421-9_6

13. Muse LA, Harris SG, Feild HS. Has the inverted-U theory of stress and job performance had a fair test? Human Performance. 2003;16(4):349–64. Available from: https://doi.org/10.1207/s15327043hup1604_2
14. Lingard H, Francis V. Does work–family conflict mediate the relationship between job schedule demands and burnout in male construction professionals and managers? Construction Management and Economics. 2005;23(7):733–45. Available from: https://doi.org/10.1080/01446190500040836
15. Chaudhari K, Sonawane A, Prasad YB, Siddiqui NA. Identification of Elements Responsible for Poor Construction Safety Culture and Their Mitigation Measures. In F. I. Khan, N. A. Siddiqui, S. M. Tauseef & B. P. Yadav (Eds). Advances in Industrial Safety. Springer. 2020;281-90. Available from: https://www.springerprofessional.de/en/identification-of-elements-responsible-for-poor-construction-saf/18395456#google_vignette
16. Joshi TK, Bhuva UB, Katoch P. Asbestos Ban in India: challenges ahead. Ann. Ann. New York Acad. Sci. 2006;1076(1):292–308. Available from: https://doi.org/10.1196/annals.1371.072
17. Rajaprasad SVS, Chalapathi PV. Factors Influencing Implementation of OHSAS 18001 in Indian Construction Organizations: Interpretive Structural Modeling Approach. Safety Health Work. 2015;6(3):200–5. Available from: https://doi.org/10.1016/j.shaw.2015.04.001
18. Singh P, Rawat C, Aggarwal V, Maskara M. "Employers" in a Migrant Intensive Industry: Organised Construction in Thane, Maharashtra. Ind. Maharashtra, Ind J Labour Econ. 2020;63:1183–1201. Available from: https://doi.org/10.1007/s41027-020-00287-6
19. Singh A, Misra SC. Safety performance & evaluation framework in Indian construction industry. Safety Science. 2021;134(105023):105023. Available from: https://doi.org/10.1016/j.ssci.2020.105023
20. Zhang S, Teizer J, Lee JK, Eastman CM, Venugopal M. Building information modeling (BIM) and safety: Automatic safety checking of construction models and schedules. Automation in Construction. 2013;29:183–95. Available from: https://doi.org/10.1016/j.autcon.2012.05.006
21. Kim K, Cho Y, Kim K. BIM-driven automated decision support system for safety planning of temporary structures. Journal of Construction Engineering and Management. 2018;144(8):04018072. Available from: https://doi.org/10.1061/(asce)co.1943-7862.0001519
22. Zhang L, Wu X, Ding L, Skibniewski M J, Lu Y. BIM-based risk identification system in tunnel construction. Journal of Civil Engineering and Management. 2016;22(4):529–39. Available from: https://doi.org/10.3846/13923730.2015.1023348
23. Abd AM, Hameed AH, Nsaif BM. Documentation of construction project using integration of BIM and GIS technique. Asian Journal of Civil Engineering. 2020;21(7):1249–57. Available from: https://doi.org/10.1007/s42107-020-00273-9
24. Khan MS, Park J, Seo J. Geotechnical property modeling and construction safety zoning based on GIS and BIM integration. Applied Sciences (Basel, Switzerland). 2021;11(9):4004. Available from: https://doi.org/10.3390/app11094004
25. Kannan MR, Santhi MH. Constructability assessment of climbing formwork systems using building information modeling. Procedia Engineering. 2013;64:1129–38. Available from: https://doi.org/10.1016/j.proeng.2013.09.191
26. Bansal VK. Application of geographic information systems in construction safety planning. International Journal of Project Management. 2011;29(1):66–77. Available from: https://doi.org/10.1016/j.ijproman.2010.01.007
27. Lota PS, Trivedi J. Site layout planning through BIM visualisation-a case study. 2020. Available from: https://doi.org/10.24928/2019/0203
28. Van-Groesen W, Pauwels P. Tracking prefabricated assets and compliance using quick response (QR) codes, blockchain and smart contract technology. Automation in Construction. 2022;141:104420. Available from: https://doi.org/10.1016/j.autcon.2022.104420
29. Cocco L, Tonelli, R, Marchesi M. A system proposal for information management in building sector based on BIM, SSI, IoT and Blockchain. Future

Internet. 2022;14(5):140. Available from: https://doi.org/10.3390/fi14050140

30. Xu J, Lu W, Wu L, Lou J, Li X. Balancing privacy and occupational safety and health in construction: A blockchain-enabled P-OSH deployment framework. Safety Science. 2022;154:105860. Available from: https://doi.org/10.1016/j.ssci.2022.105860
31. Lu W, Wu L, Xu J, Lou J. Construction E-inspection 2.0 in the COVID-19 pandemic era: A blockchain-based technical solution. J Manage Eng [Internet]. 2022;38(4). Available from: http://dx.doi.org/10.1061/(asce)me.1943-5479.0001063
32. Wu L, Lu W, Zhao R, Xu J, Li X, Xue F. Using blockchain to improve information sharing accuracy in the onsite assembly of modular construction. Journal of Management in Engineering. 2022;38(3). Available from: https://doi.org/10.1061/(asce)me.1943-5479.0001029
33. Hamledari H, Fischer M. Measuring the impact of blockchain and smart contracts on construction supply chain visibility. Adv Eng Inform [Internet]. 2021;50(101444):101444. Available from: http://dx.doi.org/10.1016/j.aei.2021.101444
34. Lingard H, Rowlinson S. *Occupational health and safety in construction project management*. London: Spon Press; 2005. Available from: https://doi.org/10.4324/9780203507919
35. Choudhry RM. Behavior-based safety on construction sites: a case study. *Accid Anal Prev*. 2014;70:14–23. Available from: https://doi.org/10.1016/j.aap.2014.03.007
36. Construction Industry Development Council (CIDC). Construction safety guidelines. New Delhi: CIDC; 2018. Available from: https://www.cidc.in/
37. World Bank. Construction sector governance and risk management. Washington (DC): World Bank; 2020. Available from: https://doi.org/10.1596/978-1-4648-1539-3
38. Hinze J, Thurman S, Wehle A. Leading indicators of construction safety performance. *Saf Sci*. 2013;51(1):23–28. Available from: https://doi.org/10.1016/j.ssci.2012.05.016
39. Deloitte. Digital transformation in construction safety. London: Deloitte Insights; 2021. Available from: https://www2.deloitte.com/us/en/pages/manufacturing/articles/digital-disruption-in-engineering-and-construction.html
40. International Labour Organization (ILO). Safety and health in construction: an ILO code of practice. Geneva: ILO; 2022.
41. Bogue R. What are the prospects for robots and drones in the construction industry? *Ind Robot*. 2018;45(1):1–6. Available from: https://doi.org/10.1108/IR-11-2017-0194
42. Health and Safety Executive (HSE). *Managing health and safety in construction (HSG150)*. 3rd ed. London: HSE; 2015. Available from: https://www.hse.gov.uk/pubns/books/hsg150.htm
43. Mohamed S. Safety climate in construction site environments. *J Constr Eng Manag*. 2002;128(5):375–384. Available from: https://doi.org/10.1061/(ASCE)0733-9364(2002)128:5(375)
44. Kerzner H. *Project management: a systems approach to planning, scheduling, and controlling*. 12th ed. Hoboken (NJ): John Wiley & Sons; 2017. ISBN: 978-1-119-16536-1.
45. Sacks R, Perlman A, Barak R. Construction safety training using immersive virtual reality. *Constr Manage Econ*. 2013;31(9):1005–1017. Available from: https://doi.org/10.1080/01446193.2013.828844
46. National Institute for Occupational Safety and Health (NIOSH). *Simple solutions: ergonomics for construction workers*. Cincinnati (OH): NIOSH; 2007. Available from: https://www.cdc.gov/niosh/docs/2007-122/
47. Guo H, Yu Y, Skibniewski MJ. Visualization technology-based construction safety management: a review. *Autom Constr*. 2017;73:135–144. Available from: https://doi.org/10.1016/j.autcon.2016.10.004
48. Clarke S. An integrative model of safety climate: linking psychological climate and work attitudes to individual safety outcomes. *J Occup Organ Psychol*. 2010;83(3):553–578. Available from: https://doi.org/10.1348/096317909X452122
49. Government of India. *National Building Code of India 2016 (SP 7:2016)*. New Delhi: Bureau of Indian Standards; 2016. Available from: National Building Code of India (NBC 2016)