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# Work-Related Musculoskeletal Disorders: A Narrative Review and Integrated Assessment Framework

**Satchidananda Mishra[1*]**
[1*]Bhubaneswar Institute of Technology, India
*Co e-mail: satchidananda.mishra@bit.edu.in[1]

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**ABSTRACT**
*Work-related musculoskeletal disorders (WMSDs) remain a major occupational health challenge, causing pain, disability, reduced productivity, and substantial economic losses. This narrative review examined occupational risk factors and ergonomic assessment methods for WMSDs and proposes an Integrated Assessment Framework to support comprehensive risk identification and intervention planning. Published studies from manufacturing, mining, construction, transportation, and manual material handling sectors were reviewed. Evidence was synthesized on WMSD prevalence, occupational exposures, and assessment approaches, including self-reported questionnaires, observational ergonomic tools, and direct biomechanical measurement techniques. Repetitive movements, forceful exertions, awkward and static postures, manual material handling, and vibration exposure were consistently identified as the principal risk factors, primarily affecting the lower back, neck, shoulders, and upper limbs. Although existing assessment methods provide valuable information, each evaluates only specific dimensions of musculoskeletal risk when applied independently. To address this limitation, an Integrated Assessment Framework was developed that combines self-reported, observational, and biomechanical assessments within a structured decision-support process linked to ergonomic interventions and continuous improvement. The framework provides a practical approach for comprehensive WMSD risk evaluation and evidence-based ergonomic decision-making. Future research should validate the framework across industrial sectors and assess its effectiveness in reducing WMSD burden and improving occupational safety and workplace sustainability.*

## INTRODUCTION

Work-related musculoskeletal disorders (WMSDs) remain a major occupational health concern across industrial sectors, affecting worker well-being, productivity, and organizational performance. The increasing complexity of workplace exposures has highlighted the need for comprehensive approaches to identifying, assessing, and managing musculoskeletal risks. This review examined the burden of WMSDs in industrial environments, evaluates key occupational risk


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factors and assessment methods, and proposes an integrated framework to support evidence-based ergonomic interventions and occupational safety and health management.

**1. Musculoskeletal Disorders and Their Global Burden**

Musculoskeletal disorders (MSDs) comprise a broad group of conditions affecting muscles, tendons, ligaments, joints, peripheral nerves, and intervertebral discs, resulting in pain, functional limitations, disability, and reduced quality of life (Gómez-Galán et al., 2017). Collectively, MSDs represent one of the most significant global public health challenges, encompassing more than 150 conditions, including low back pain, osteoarthritis, rheumatoid arthritis, neck disorders, sarcopenia, fractures, and connective tissue diseases. Recent estimates indicate that approximately 1.71 billion people worldwide are affected by MSDs, making them the leading contributor to rehabilitation needs and a major cause of disability and productivity loss across populations (Lee et al., 2025).

**2. Work-Related Musculoskeletal Disorders in Industrial Environments**

Within industrial establishments, WMSDs constitute one of the most prevalent occupational health problems. WMSDs arise when workplace exposures exceed the body's physiological capacity for recovery, leading to cumulative damage of musculoskeletal tissues over time. Common occupational risk factors include manual material handling, repetitive movements, forceful exertion, awkward or sustained postures, vibration exposure, and prolonged standing or sitting. These exposures are widespread across manufacturing, construction, mining, transportation, warehousing, healthcare, and office-based occupations, contributing to increased absenteeism, reduced productivity, compensation costs, and diminished worker well-being (Da Costa & Vieira, 2010; Soares et al., 2020).

**3. Assessment of WMSD Risk and Existing Methodological Challenges**

WMSDs are multifactorial conditions arising from the interaction of biomechanical, organizational, environmental, and individual factors. Because workers are often exposed to multiple ergonomic hazards simultaneously, comprehensive assessment approaches are required to accurately identify musculoskeletal risk.

Common assessment methods include self-reported instruments such as the Nordic Musculoskeletal Questionnaire (NMQ), observational tools including the Ovako Working Posture Analysis System (OWAS), Rapid Upper Limb Assessment (RULA), Rapid Entire Body Assessment (REBA), and Quick Exposure Check (QEC), and direct biomechanical techniques such as goniometry and electromyography (EMG). While these methods provide valuable information on symptoms, ergonomic exposures, and physiological responses, they are frequently applied independently, resulting in fragmented risk assessment and potentially incomplete evaluation of occupational musculoskeletal hazards (Dul et al., 2012; Forman et al., 2024).

Although numerous ergonomic assessment tools have been developed to evaluate work-related musculoskeletal disorders, most existing approaches focus on specific dimensions of risk, such as worker-reported symptoms, postural exposures, repetitive movements, forceful exertions, or biomechanical loading. Consequently, assessments are frequently conducted in isolation, resulting in fragmented risk characterisation and limited comparability across occupational settings. This methodological separation may lead to inconsistent risk classification, incomplete understanding of exposure–response relationships, and difficulties in prioritizing ergonomic interventions. Furthermore, existing frameworks generally emphasize risk identification rather than the systematic integration of multiple evidence streams into a unified decision-making process.

Therefore, a gap remains for a structured approach capable of combining subjective, observational, and biomechanical assessment outputs to support comprehensive ergonomic evaluation and intervention planning. This review addresses that gap by synthesizing current evidence on WMSDs and proposing an Integrated Assessment Framework that supports risk triangulation, intervention prioritization, and continuous improvement within occupational safety and health management systems.

### 4. Research Gap and Objectives

Despite advances in occupational ergonomics, there remains a need for integrated assessment approaches that combine subjective, observational, and biomechanical evidence to support comprehensive WMSD risk identification and intervention planning. This need is particularly important in industrial environments where workers are exposed to multiple ergonomic hazards simultaneously.

Accordingly, this review aims to: (i) examine the occurrence and patterns of WMSDs among industrial workers; (ii) identify major occupational risk factors; (iii) evaluate commonly used assessment methods; and (iv) propose an Integrated Assessment Framework that combines self-reported, observational, and biomechanical approaches to support evidence-based ergonomic interventions and occupational safety and health (OSH) management. By synthesizing current evidence, the review seeks to advance the assessment, prevention, and management of WMSDs in industrial environments.

The principal contribution of this review is the development of an Integrated Assessment Framework that systematically combines self-reported, observational, and biomechanical evidence into a unified decision-support process for WMSD risk assessment and intervention planning.

## METHODS

This study employed a narrative literature review with thematic synthesis to examine the occurrence, occupational risk factors, assessment methods, and management strategies for WMSDs. Evidence from diverse industrial sectors was synthesized to identify recurring themes related to WMSD prevalence, risk factors, assessment approaches, and prevention strategies. Based on this synthesis, an Integrated Assessment Framework was developed to support comprehensive ergonomic risk evaluation, intervention planning, and occupational safety and health decision-making.

### 1. Literature Search Strategy

A structured literature search was conducted using the electronic databases Scopus, Web of Science, PubMed, and Google Scholar. Publications published between 2000 and 2026 were considered. Search terms included combinations of "work-related musculoskeletal disorders", "WMSDs", "occupational ergonomics", "industrial workers", "manual material handling", "repetitive motion", "ergonomic assessment", "occupational risk factors", "OWAS", "RULA", "REBA", "QEC", "electromyography", and "goniometry". Additional relevant studies were identified through manual screening of the reference lists of eligible articles to identify potentially relevant publications not captured during the database search. The literature search was conducted between January and March 2026.

## 2. Eligibility Criteria and Study Selection

Studies were included if they were published in English, available in full text, and reported work-related musculoskeletal disorders (WMSDs), ergonomic risk factors, assessment methods, or intervention strategies among occupational or industrial worker populations. Studies focusing on non-occupational musculoskeletal conditions, lacking relevance to workplace ergonomic exposures, duplicate publications, unavailable full texts, or insufficient methodological information were excluded.

The literature search identified a total of 60 records, including 54 records retrieved from electronic databases (Scopus, n = 20; Web of Science, n = 14; PubMed, n = 9; and Google Scholar, n = 11) and 6 additional records identified through reference list screening (n = 5) and other sources (n = 1). After removing 8 duplicate records, 52 records remained for title and abstract screening. Following the initial screening, 20 records were excluded based on the predefined eligibility criteria. The remaining 32 full-text articles were assessed for eligibility, of which 4 articles were excluded because they were unavailable in full text or were not relevant to the review objectives. Consequently, 28 studies were included in the qualitative narrative synthesis. The study selection process is illustrated in the PRISMA-style flow diagram (Figure 1).

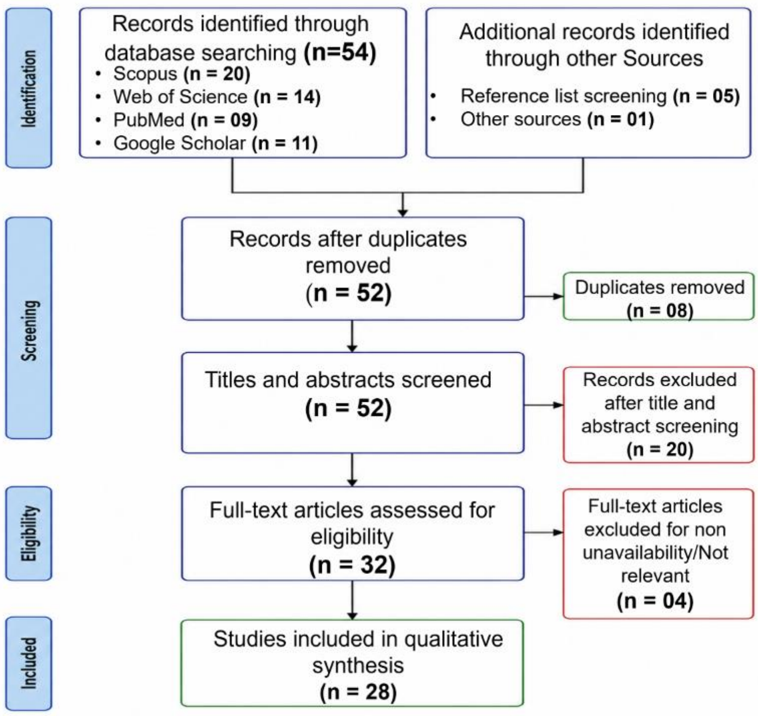


**Figure 1. PRISMA-style Flow Diagram of Literature Identification, Screening, Eligibility Assessment, and Study Inclusion Process**

## 3. Data Extraction

Data were systematically extracted from each eligible study using a predefined extraction framework. Information collected included occupational sector, worker population, WMSD prevalence, affected body regions, occupational exposures, ergonomic risk factors, assessment methods, intervention strategies, and principal findings.

## 4. Data Synthesis and Framework Development

The extracted evidence was analyzed using thematic synthesis. Findings were organized into three principal domains: (i) prevalence and distribution of WMSDs among industrial workers, (ii) occupational risk factors associated with WMSDs, and (iii) assessment methods used for WMSD evaluation. Assessment approaches were further classified into self-reported methods, observational ergonomic assessment tools, and direct biomechanical measurements. Self-reported methods included the NMQ, symptom diaries, and structured interviews. Observational methods included the OWAS, RULA, REBA, and QEC. Direct biomechanical measurements included goniometry and EMG.

Relationships among identified themes were examined to identify recurring patterns, methodological limitations, and opportunities for improving occupational risk assessment. Based on the thematic synthesis, an Integrated Assessment Framework was developed by integrating evidence on occupational risk factors, assessment methods, and intervention pathways. The framework combines subjective, observational, and biomechanical assessments to support risk identification, intervention planning, and continuous improvement of occupational safety and health practices.

## 5. Quality Considerations

Although conducted as a narrative review, methodological rigor was enhanced through a structured literature search, predefined eligibility criteria, documented screening procedures, and PRISMA-style reporting. The included studies were qualitatively appraised using predefined criteria, including methodological clarity, relevance to the review objectives, appropriateness of study design, use of validated assessment methods, adequacy of sample size where applicable, and applicability to industrial settings. These criteria were applied consistently during evidence synthesis to evaluate the credibility, methodological robustness, and practical relevance of the included studies. Greater emphasis was placed on evidence derived from studies employing appropriate study designs, validated ergonomic assessment methods, clear methodological reporting, and adequate sample sizes. This qualitative appraisal informed the interpretation and synthesis of the evidence rather than formal quality scoring or study exclusion. Owing to the narrative design, formal risk-of-bias assessment and meta-analysis were not performed.

## 6. Ethics Statement

This study was based exclusively on the review and synthesis of published literature and did not involve human participants, animals, personal data, or primary data collection. Therefore, ethical approval and informed consent were not required.

## RESULTS

The reviewed literature shows that WMSDs are prevalent across industrial occupations and result from multiple occupational exposures. Repetitive movements, manual material handling, awkward postures, forceful exertions, vibration, and prolonged static work were the most common risk factors. The type and anatomical distribution of WMSDs vary with occupational demands, while assessment methods range from self-reported questionnaires to biomechanical measurements. Overall, the evidence highlights the multifactorial nature of WMSDs and the need for integrated assessment and prevention strategies (Oakman et al., 2025; Soares et al., 2020). Table 1 highlights representative studies underpinning the thematic synthesis presented in this review.

**Table 1. Characteristics of Representative Studies Included in the Narrative Review**

| Author (Year) | Occupational Setting | Assessment Focus | Principal Findings / Contribution |
|---|---|---|---|
| Kuorinka et al. (1987) | General workforce | Symptom assessment (NMQ) | Developed the NMQ for standardized musculoskeletal symptom surveillance |
| Karhu et al. (1977) | Industrial workers | Working posture (OWAS) | Developed the OWAS method for postural risk assessment. |
| McAtamney & Corlett (1993) | Industrial tasks | Upper-limb posture (RULA) | Introduced rapid upper-limb ergonomic assessment. |
| Hignett & McAtamney (2000) | Healthcare/Industry | Whole-body posture (REBA) | Developed a whole-body ergonomic assessment method for dynamic work tasks. |
| Da Costa & Vieira (2010) | Multiple occupations | Occupational risk factors | Confirmed associations between ergonomic exposures and WMSDs. |
| Andersen et al. (2008) | Office workers | Muscle activity (EMG) | Linked sustained muscle loading to neck and shoulder disorders. |
| Chen et al. (2017) | Gas-cylinder handlers | WMSD prevalence | Linked manual handling to shoulder, neck, and low-back disorders. |
| Dave et al. (2021) | Construction workers | Lumbar disorders | Linked heavy manual work to lumbar degeneration. |
| Forman et al. (2024) | Industrial ergonomics | Biomechanical assessment | Highlighted wearable technologies for ergonomic assessment. |
| Oakman et al. (2025) | Multiple industries | Prevention strategies | Emphasized integrated WMSD prevention and management. |

The representative studies summarized in Table 1 form the evidence base for the thematic synthesis presented below. The following sections discuss the prevalence of WMSDs, associated occupational risk factors, assessment methods, and prevention strategies identified across diverse industrial settings.

## 1. Musculoskeletal Disorders among Industrial Workers

The reviewed literature indicates that WMSDs are highly prevalent across diverse industrial occupations, including construction, manufacturing, mining, transportation, healthcare, warehousing, vibration-exposed work, and computer-based occupations. Common disorders include low back pain, lumbar disc degeneration, osteoarthritis, neck and shoulder disorders, upper-limb musculoskeletal disorders, knee disorders, tendinopathies, and carpal tunnel syndrome, with their occurrence strongly influenced by occupational exposures and work demands.

The lower back, neck, shoulders, and upper limbs were the most frequently affected body regions. Manual material handling and heavy physical work were mainly associated with low back and shoulder disorders, whereas repetitive tasks and prolonged static postures were linked to neck, upper-limb disorders, and carpal tunnel syndrome. Vibration exposure increased the risk of spinal and joint disorders, while prolonged standing, kneeling, and awkward postures contributed to knee and lower-limb disorders. Table 2 summarises the major occupational groups, prevalent WMSDs, and associated risk factors identified in the reviewed literature.

**Table 2. Occupational Risk Factors and Prevalent Pathologies**

| Occupational Category | Prevalent Pathology | Likely Cause |
|---|---|---|
| Construction workers and helpers | Low back pain, lumbar disc degeneration, shoulder disorders, knee disorders | Heavy lifting, manual material handling, awkward postures, repetitive tasks |
| Manufacturing and industrial workers | Low back pain, neck disorders, shoulder disorders, upper-limb musculoskeletal disorders | Repetitive movements, prolonged standing, forceful exertions, awkward postures |
| Vibration-exposed workers | Neck and upper-limb disorders, elbow and wrist disorders | Hand–arm vibration, heavy loads, static postures |
| Kneeling-intensive work | Knee disorders, meniscal injuries | Prolonged kneeling, repetitive knee loading, awkward postures |
| Computer and office workers | Neck/shoulder disorders, upper-limb musculoskeletal disorders, carpal tunnel syndrome | Prolonged computer use, static postures, repetitive movements, poor workstation ergonomics |
| Textile and garment workers | Neck disorders, shoulder disorders, low back pain, upper-limb musculoskeletal disorders | Repetitive movements, prolonged sitting, static postures, awkward upper-limb postures |
| Healthcare workers | Low back pain, shoulder disorders, neck disorders, upper-limb musculoskeletal disorders | Patient handling, repetitive movements, awkward postures, prolonged standing |

Workers exposed to hand–arm and whole-body vibration demonstrated an increased prevalence of upper-limb musculoskeletal disorders, osteoarthritis, reduced grip strength, and degenerative joint changes. Studies among foundry workers, quarry workers, and miners also reported reduced joint mobility, chronic pain, and increased musculoskeletal symptoms associated with prolonged vibration exposure (Bovenzi et al., 1987; Qamruddin et al., 2022; Sakakibara et al., 1993; Sun et al., 2024).

Physically demanding work among machine operators, carpenters, foundry workers, construction workers, and manual labourers was strongly associated with lumbar disc degeneration, altered cervical alignment, vertebral changes, and chronic low back pain resulting from prolonged loading and repetitive mechanical stress (Dave et al., 2021; Luoma et al., 1998). Similarly, occupational kneeling, squatting, repetitive lifting, and overhead work increased the prevalence of knee disorders, meniscal injuries, shoulder pain, and muscular fatigue, particularly among welders, gas-cylinder handlers, construction workers, and floor workers (Chen et al., 2017; Herberts & Kadefors, 1976). Neck and upper-limb musculoskeletal disorders were common among workers performing repetitive or precision tasks, including computer users, textile workers, healthcare personnel, and manufacturing workers. Repetitive hand movements, sustained static postures, prolonged computer use, forceful exertions, and poor ergonomics were the principal risk factors. Electromyographic studies showed increased muscle activation and reduced recovery among symptomatic workers (Andersen et al., 2008; Yuk Szeto et al., 2009).

## 2. Occupational Risk Factors for Work-Related Musculoskeletal Disorders

Analysis of the reviewed studies identified six major physical risk factors contributing to WMSDs across industrial sectors: manual material handling, repetitive movements, awkward postures, forceful exertions, vibration exposure, and prolonged static postures. These exposures often coexist, increasing biomechanical loading on the musculoskeletal system and the risk of injury (Bernard, 1997; Da Costa & Vieira, 2010). Table 3 summarises the principal physical risk factors and representative industrial activities associated with WMSDs.

**Table 3. Key Physical Risk Factors for WMSDs in Industrial Settings**

| Risk Factor | Description | Typical Industrial Examples |
|---|---|---|
| Manual material handling | Lifting, carrying, pushing, pulling | Low back pain, shoulder disorders |
| Repetitive movements | Repetitive manual tasks | Neck disorders, upper-limb disorders, tendinopathies |
| Awkward postures | Bending, twisting, overhead work | Low back, shoulder, and knee disorders |
| Forceful exertions | High-force manual tasks | Tendinopathies, upper-limb disorders |
| Vibration exposure | Hand–arm or whole-body vibration | Upper-limb disorders, spinal disorders, joint degeneration |
| Prolonged static postures | Sustained sitting or standing | Neck disorders, low back pain, lower-limb disorders |

The findings indicate that WMSD risk results from cumulative exposure, with duration, intensity, frequency, and recovery influencing injury development. Although RULA, REBA, OWAS, and QEC are widely used, their performance varies with task complexity and exposure type. Agreement between observational scores and musculoskeletal outcomes is stronger for repetitive upper-limb tasks but more variable in dynamic work environments such as construction and logistics. These findings support integrated ergonomic risk assessment and workplace-specific interventions.

## 3. Assessment Methods for Work-Related Musculoskeletal Disorders

The reviewed literature identified three principal approaches for WMSD assessment: self-reported methods, observational ergonomic assessments, and direct biomechanical measurements, each providing complementary information on symptoms, ergonomic exposures, and physiological responses. Self-reported methods, including the NMQ, symptom diaries, and structured interviews, were widely used to identify musculoskeletal symptoms and discomfort patterns (Kuorinka et al., 1987). Observational tools, such as OWAS, RULA, REBA, and QEC, assessed postures, repetitive movements, forceful exertions, and other ergonomic hazards (Hignett & McAtamney, 2000; Karhu et al., 1977; McAtamney & Corlett, 1993). Direct biomechanical methods, including goniometry and EMG, quantified joint motion, muscle activity, and fatigue, providing objective validation of observational findings (Cifrek et al., 2009; Forman et al., 2024). Biomechanical methods offer objective evaluation of muscular loading but require greater technical expertise and resources. In contrast, self-reported methods provide broad population coverage but are susceptible to recall bias, whereas observational tools offer a practical balance between accuracy and feasibility. Table 4 summarises common WMSDs, affected body regions, occupational causes, and recommended assessment methods. Method selection should consider task characteristics, exposure complexity, available resources, and assessment objectives.

**Table 4. WMSDs – Industrial Causes and Assessment Methods**

| MSD Type | Affected Body Part | Common Industrial Causes | Recommended Assessment Methods |
|---|---|---|---|
| Lower back pain | Lumbar spine | Manual lifting, bending, awkward posture, prolonged standing | REBA, OWAS, Functional capacity tests, Self-reported pain (NMQ) |
| Neck and shoulder disorders | Cervical spine, shoulders | Overhead work, repetition, static postures | RULA, REBA, Goniometry, EMG, Symptom diary |
| Carpal tunnel syndrome | Wrist, hand | Repetitive hand/wrist motions, forceful grip | Strain Index, Grip/pinch dynamometry, NMQ, Clinical examination |
| Tendinitis / Epicondylitis | Elbows, forearms, shoulders | Repetitive forceful tasks, vibration | Strain Index, RULA, EMG, Worker self-reports |
| Knee and hip problems | Knees, hips | Squatting, kneeling, heavy lifting | REBA, OWAS, Functional mobility tests, Symptom reporting |
| Whole-body fatigue / MSDs | Muscles, joints | Vibration exposure, prolonged static posture | EMG, Posture observation, REBA, Health surveillance |

No single assessment method adequately captures WMSD risk. Integrating self-reported, observational, and biomechanical approaches provides a more comprehensive evaluation and forms the basis of the proposed integrated assessment framework.

## DISCUSSION

The evidence synthesized in this review confirms that, despite advances in ergonomics and occupational health, WMSDs remain a leading cause of occupational injury, disability, reduced productivity, and lost work time across industrial sectors worldwide. Their continuing human and economic burden underscores the need for more comprehensive approaches to risk assessment and prevention. Although the anatomical manifestations of WMSDs differ among occupations, a consistent pattern emerges in which repetitive movements, forceful exertion, awkward postures, vibration exposure, prolonged static work, and insufficient recovery periods interact to produce cumulative biomechanical stress. These factors rarely act in isolation; rather, they operate synergistically, increasing tissue loading beyond physiological recovery capacity and ultimately contributing to musculoskeletal injury and functional impairment. The evidence reviewed suggests that WMSDs should be viewed through a systems-based perspective that recognizes the interaction between worker characteristics, task demands, workplace design, and organizational conditions (Oakman et al., 2025; Soares et al., 2020).

### 1. Occupational Patterns and Body Region Vulnerability

A notable finding from the reviewed literature is the strong association between occupational exposure profiles and the anatomical distribution of WMSDs. Different occupations expose workers to distinct biomechanical demands, resulting in characteristic patterns of musculoskeletal injury. Workers engaged in construction, material handling, mining, and heavy industrial operations predominantly experience lower back disorders due to repetitive lifting, forceful exertion, carrying loads, awkward trunk postures, and whole-body vibration exposure. Studies involving construction workers, foundry workers, and manual labourers consistently report elevated prevalence of lumbar disc degeneration, chronic low back pain, and spinal loading-related disorders (Dave et al., 2021; Luoma et al., 1998). Similarly, professional drivers represent a particularly vulnerable group, with low back pain prevalence frequently exceeding 50%, largely attributable to prolonged sitting, vehicle vibration, constrained postures, and extended working hours (Gopakumar et al., 2025; Sheth et al., 2023). In contrast, occupations requiring repetitive upper-limb activity demonstrate greater vulnerability to neck, shoulder, elbow, and wrist disorders. Welders, assembly-line operators, machine operators, and gas-cylinder handlers frequently experience shoulder fatigue, tendon disorders, and upper-limb musculoskeletal symptoms resulting from repetitive arm movements, overhead work, static muscular loading, and forceful exertion. For example, gas-cylinder handlers reported a one-year WMSD prevalence of approximately 91%, with the shoulders, neck, and lower back identified as the most affected regions (Chen et al., 2017). Likewise, electromyographic investigations among welders have demonstrated localized fatigue of the deltoid, trapezius, and supraspinatus muscles during prolonged overhead work, highlighting the direct relationship between task-specific demands and muscular overload (Herberts & Kadefors, 1976).

The growing digitalisation of work has also shifted attention toward computer-based occupations. Office workers and computer users commonly experience neck, shoulder, and upper-limb disorders associated with prolonged sitting, static postures, repetitive keyboard and mouse use, and inadequate workstation design. EMG studies have demonstrated sustained cervical muscle activation and reduced muscular recovery periods among symptomatic computer users, suggesting that even low-force repetitive activities can generate significant cumulative musculoskeletal strain over time (Andersen et al., 2008; Yuk Szeto et al., 2009). Collectively, these findings indicate that WMSDs are not merely occupation-specific disorders but exposure-specific syndromes, with distinct combinations of biomechanical stressors determining the vulnerability of specific body regions. This exposure-based perspective supports targeted ergonomic interventions and assessment models that prioritize dominant risk exposures rather than occupational categories alone.

**2. Limitations of Existing Assessment Approaches**

Despite advances in ergonomic assessment, no single method provides a comprehensive evaluation of WMSD risk. Existing approaches typically focus on specific dimensions of exposure, resulting in fragmented risk characterisation and potentially incomplete intervention strategies.

Self-reported instruments, such as the NMQ, symptom diaries, and structured interviews, are widely used because they are cost-effective and capable of identifying discomfort and symptom patterns (Kuorinka et al., 1987). However, they primarily reflect worker perceptions and health outcomes and may be influenced by recall bias and psychosocial factors (Rasmussen et al., 2018).

Observational methods, including OWAS, RULA, REBA, and QEC, assess postures, repetitive movements, forceful exertions, and task characteristics, supporting the identification of ergonomic hazards and workstation redesign (Hignett & McAtamney, 2000; Karhu et al., 1977; McAtamney & Corlett, 1993). These methods are particularly suitable for routine workplace screening and ergonomic risk prioritization but provide only indirect estimates of biomechanical stress. Direct biomechanical techniques, including goniometry and EMG, objectively measure joint motion, muscle activity, workload, and fatigue (Cifrek et al., 2009; Forman et al., 2024). Although more resource-intensive, they are especially valuable for detailed investigation of complex or high-risk tasks and for validating observational findings (Yuk Szeto et al., 2009).

The limitations of individual methods become evident in complex industrial settings where multiple risk factors coexist. Workers may report discomfort, receive moderate observational risk scores, yet demonstrate substantial muscular fatigue through EMG, illustrating the multidimensional nature of WMSD risk. The reviewed literature therefore indicates that the primary limitation is not the availability of assessment tools but the absence of a structured approach for integrating self-reported, observational, and biomechanical evidence. A systematic framework combining these complementary methods can improve risk identification, intervention prioritization, and evidence-based ergonomic decision-making, providing the foundation for the Integrated Assessment Framework proposed in the subsequent section.

**3. Integrated Assessment Framework for WMSDs**

A major finding of this review is that existing WMSD assessment approaches are frequently applied in isolation, resulting in fragmented risk evaluation and limited decision-making. Self-reported instruments, observational ergonomic assessments, and biomechanical techniques each provide valuable but complementary information on worker symptoms, ergonomic exposures, and physiological responses; however, no single method adequately captures the multidimensional nature of occupational musculoskeletal risk. To address this limitation, the present review proposes an Integrated Assessment Framework for WMSDs that systematically integrates these three evidence streams within a six-layer decision-support architecture. The framework enables risk triangulation, intervention prioritization, and continuous improvement within occupational safety and health management systems (Figure 2), thereby supporting more comprehensive and evidence-based ergonomic decision-making.

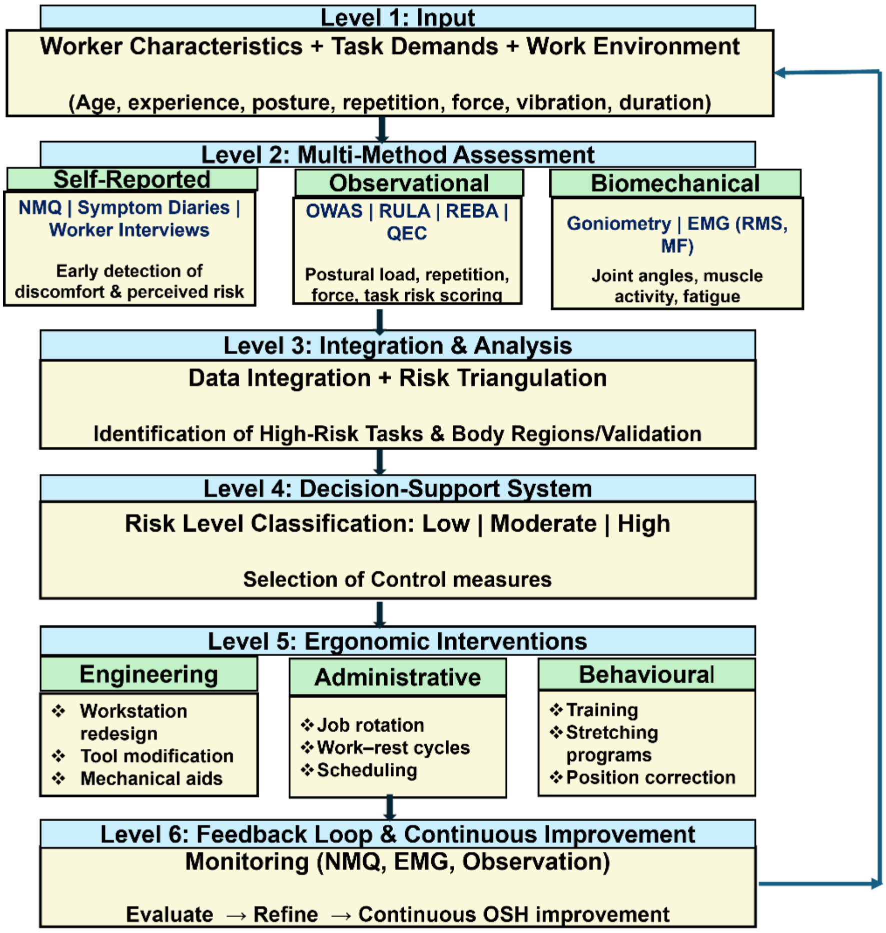


**Figure 2. Integrated Six-Layer Assessment Framework for WMSD Risk Identification, Triangulation, Intervention Selection, and Continuous Improvement**

The framework comprises six sequential layers that support a systematic and integrated approach to WMSD risk assessment and management. The first three layers combine self-reported assessments (e.g., NMQ, symptom diaries, and structured interviews), observational ergonomic methods (OWAS, RULA, REBA, and QEC), and direct biomechanical measurements (goniometry and electromyography). Together, these complementary approaches provide information on worker symptoms, ergonomic exposures, postural risks, joint motion, muscle activity, workload, and fatigue, thereby enabling a comprehensive evaluation of musculoskeletal risk (Cifrek et al., 2009; Forman et al., 2024; Hignett & McAtamney, 2000; Karhu et al., 1977; Kuorinka et al., 1987; McAtamney & Corlett, 1993). The remaining layers integrate these assessment outputs through risk triangulation, link the findings to appropriate ergonomic interventions using a structured decision-support process, and promote continuous monitoring through feedback and reassessment. This integrated approach improves confidence in risk classification while supporting systematic ergonomic decision-making and continual improvement within occupational safety and health management systems. Table 5 presents a decision matrix for selecting assessment methods according to task characteristics and exposure conditions, supporting consistent evidence-based ergonomic evaluation.

**Table 5. Decision Matrix for Selecting WMSD Assessment Tools**

| Task Type | Tool(s) | Rationale |
|---|---|---|
| Static upper limb work | RULA | Focused upper limb assessment |
| Whole-body dynamic tasks | REBA | Captures posture and load |
| Repetitive/forceful tasks | QEC | Includes repetition and perception |
| Heavy lifting | NIOSH + REBA | Quantitative + postural analysis |
| Prolonged postures | OWAS | Suitable for duration-based risk |
| High-precision studies | EMG + Goniometry | Objective validation |
| Driving/vibration | QEC | Captures vibration exposure |

The proposed framework is scalable across diverse industrial settings. Resource-constrained workplaces may rely primarily on questionnaires and observational tools, whereas technology-enabled environments can incorporate wearable sensors, real-time EMG, computer vision, and data analytics. By integrating worker-reported, observational, and biomechanical evidence within a single decision-support process, the framework provides a practical foundation for improved WMSD risk identification, intervention prioritization, and continuous ergonomic improvement.

**a. Contribution of the Integrated Assessment Framework**

Unlike conventional ergonomic assessment approaches that primarily rely on a single assessment method, such as the NMQ, OWAS, RULA, REBA, or QEC, the proposed framework does not introduce a new assessment instrument. Instead, its contribution lies in providing a structured approach for sequentially integrating self-reported, observational, and biomechanical evidence within a unified decision-support process. This integrated approach facilitates risk triangulation, supports intervention prioritization, and enables continuous feedback for ergonomic risk management.

The framework bridges the gap between fragmented ergonomic assessments and integrated occupational decision-making by linking complementary assessment methods with intervention planning and feedback mechanisms. Its scalable design enables implementation in both resource-constrained workplaces using conventional ergonomic tools and technology-enabled environments incorporating wearable sensors, computer vision, and biomechanical monitoring. Accordingly, the framework serves as an evidence-informed conceptual model for comprehensive WMSD risk assessment and occupational safety and health decision-making across diverse industrial settings. It is intended to support ergonomic practice and future validation studies rather than to function as a validated assessment tool.

## 4. Management and Prevention Strategies

Effective prevention and management of WMSDs require a comprehensive approach based on the Hierarchy of Controls, emphasizing hazard elimination, engineering controls, administrative measures, and behavioral interventions (Dul et al., 2012; Oakman et al., 2025). Elimination and substitution strategies, such as automation, mechanized material handling, and process redesign, offer the greatest potential for reducing exposure to ergonomic hazards. Engineering controls, including adjustable workstations, assistive lifting devices, ergonomic tools, and workstation redesign, can effectively reduce awkward postures, excessive force, repetitive movements, and vibration exposure (Mulimani et al., 2018).

Administrative measures, such as job rotation, workload management, and structured work–rest schedules, help reduce cumulative musculoskeletal loading and support worker recovery, while behavioral interventions improve awareness and safe work practices (Dul et al., 2012; Oakman et al., 2025). Participatory ergonomics further strengthens prevention efforts by involving workers in hazard identification and solution development. In addition, emerging technologies, including wearable sensors, computer vision systems, and real-time biomechanical monitoring, provide new opportunities for continuous risk assessment and data-driven ergonomic management (Forman et al., 2024). Table 6 summarises key intervention strategies for common WMSD-related risk factors. Overall, the evidence suggests that integrated, multi-level interventions are more effective than isolated control measures in reducing musculoskeletal risks and improving occupational health outcomes (Dul et al., 2012; Forman et al., 2024; Oakman et al., 2025).

**Table 6. Management Strategies for WMSDs**

| WMSD / Region | Key Risk Factors | Interventions | Outcomes |
|---|---|---|---|
| Lower back | Lifting, awkward posture | Mechanical aids, redesign, training | Reduced spinal load |
| Neck/shoulder | Static posture, repetition | Adjustable workstations, breaks | Reduced strain |
| Upper limb | Repetition, force | Tool redesign, task variation | Lower stress |
| Whole-body fatigue | Prolonged standing | Work–rest cycles, anti-fatigue mats | Reduced fatigue |
| Vibration-related | Vibrating tools, driving | Low-vibration tools, PPE | Reduced exposure |
| Complex cases | Multiple risks | Integrated interventions | Comprehensive control |

Ultimately, sustainable prevention of WMSDs requires collaboration among workers, supervisors, engineers, ergonomists, and occupational health professionals. Such multidisciplinary engagement ensures that interventions remain practical, evidence-based, and adaptable to evolving workplace conditions, thereby contributing to improved worker well-being, enhanced productivity, and safer industrial operations. Together, these components form a systems-based prevention strategy integrating ergonomic design, organizational practices, worker participation, and technological innovation. While engineering controls reduce physical exposure, their effectiveness is strengthened through administrative support, worker involvement, and continuous monitoring, making integrated strategies more effective than isolated measures. Table 6 summarises management strategies for WMSDs according to major risk factors and affected body regions. Figure 3 extends these strategies into a systems-based prevention framework by integrating ergonomic risk assessment, intervention selection, implementation, monitoring, and continuous feedback. This framework links engineering, administrative, and participatory controls within a continuous improvement cycle to support adaptive and evidence-based management of WMSD risks across diverse industrial settings.

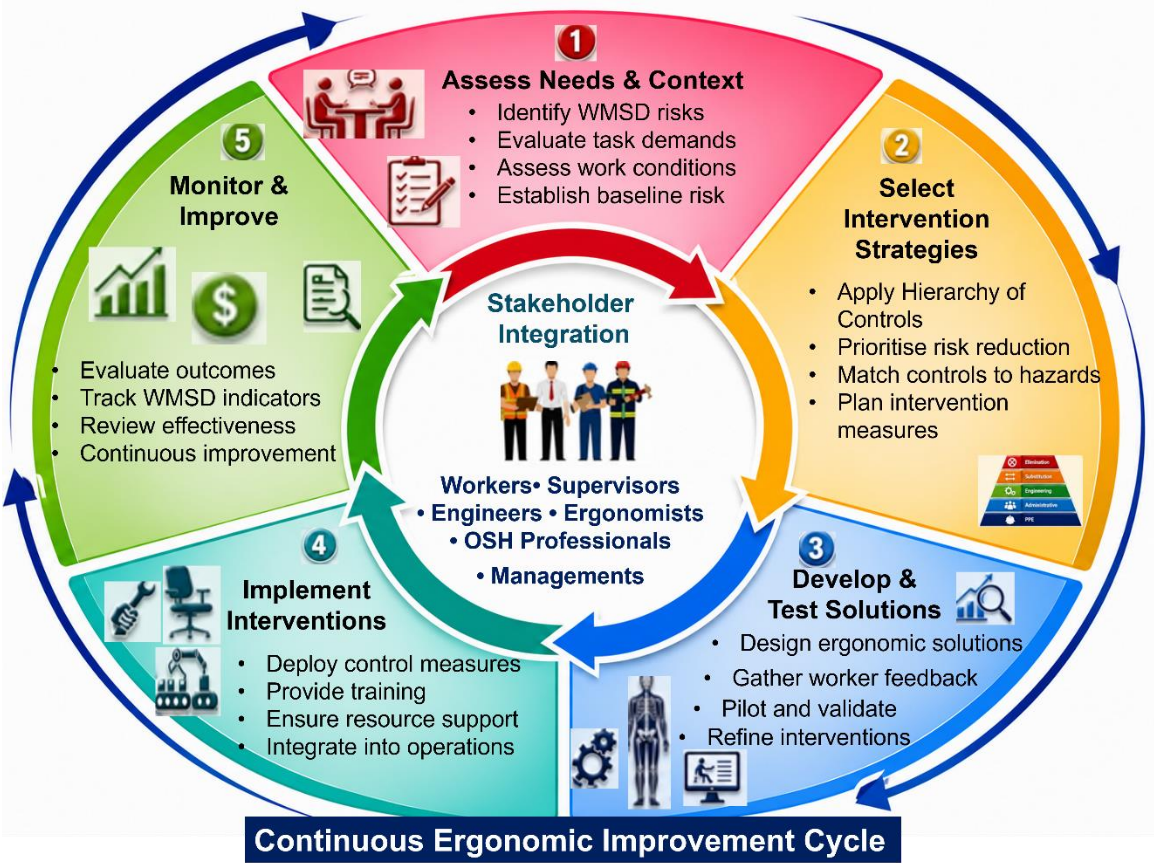


**Figure 3. Systems-based framework for WMSD assessment, intervention, and continuous improvement. [Conceptual adaptation from (Nayak et al., 2026)]**

## 5. Implications for Industrial Practice and Future Research

This review highlights limitations in current OSH and ergonomic practices, where isolated assessment methods fail to capture the combined influence of biomechanical, organizational, and individual risk factors. The proposed Integrated Assessment Framework addresses this gap by integrating self-reported, observational, and biomechanical approaches to support comprehensive risk evaluation and evidence-based interventions. The framework is scalable across diverse industrial settings, allowing large organizations to incorporate advanced technologies such as wearable sensors, electromyography, and computer vision systems, while enabling small and medium-sized enterprises to rely on questionnaires and observational tools according to available resources. Future research should validate the framework across industrial sectors, develop sector-specific implementation protocols, and undertake comparative and longitudinal studies to evaluate long-term effectiveness and practical performance.

## 6. Analytical Implications Across Industrial Sectors

Comparison of the reviewed studies indicates that WMSD risk patterns are generally consistent across industrial sectors, although the dominant exposure mechanisms vary according to work characteristics. Manufacturing and assembly-line occupations are primarily affected by repetitive upper-limb movements and static postures, whereas construction, mining, and logistics involve greater risks from manual material handling, forceful exertions, and whole-body loading. Office-based occupations predominantly experience neck and upper-limb disorders associated with prolonged sitting and repetitive computer use, while vibration-exposed industries exhibit additional risks related to cumulative joint degeneration and reduced neuromuscular function. These findings suggest that although WMSDs arise from multiple interacting factors, assessment and intervention strategies should be adapted to sector-specific exposure profiles.

The review also demonstrates that assessment methods differ in their suitability for specific work environments. RULA is most appropriate for evaluating upper-limb postures and repetitive seated or precision tasks, whereas REBA is better suited for dynamic whole-body activities involving lifting, bending, and material handling. OWAS provides useful assessment of prolonged working postures, while QEC is advantageous when repetition, force, vibration, and worker perception require simultaneous consideration. Direct biomechanical techniques such as EMG and goniometry are particularly valuable where objective quantification of muscle loading, fatigue, or intervention validation is required, although their routine application may be constrained by cost and technical expertise. Accordingly, observational tools are appropriate for routine workplace screening, whereas biomechanical methods are most beneficial for high-risk tasks, detailed ergonomic investigations, and evaluation of intervention effectiveness.

From an implementation perspective, the proposed framework is sufficiently flexible to accommodate different organizational capacities. Small and medium-sized enterprises can apply the framework using self-reported questionnaires and observational tools as initial screening methods, reserving advanced biomechanical assessments for high-risk tasks or specialist investigations. In contrast, larger organizations with greater technical resources may integrate wearable sensors, computer vision systems, and real-time biomechanical monitoring to support continuous ergonomic surveillance. This scalable implementation strategy enhances the practical applicability of the framework across diverse industrial settings while maintaining a consistent evidence-based approach to musculoskeletal risk management.

Despite the consistent evidence identifying repetitive movements, awkward postures, forceful exertions, manual material handling, vibration exposure, and prolonged static work as major contributors to WMSDs, considerable heterogeneity exists across studies with respect to occupational settings, study designs, exposure assessment methods, and outcome measures. Such variability limits direct comparison among studies and highlights the need for greater standardization in ergonomic assessment protocols. Furthermore, the predominance of cross-sectional studies restricts causal inference, emphasizing the need for longitudinal and intervention-based research to better establish exposure–response relationships and evaluate the effectiveness of preventive strategies. Future research should also explore the integration of emerging technologies, such as wearable sensors and computer vision, with conventional ergonomic assessment methods to improve the accuracy and practicality of WMSD risk assessment.

While the reviewed evidence consistently supports an association between occupational ergonomic exposures and WMSDs, the strength of the evidence varies owing to differences in study design, methodological quality, sample characteristics, and assessment approaches. In addition, the predominance of cross-sectional studies and self-reported assessments introduces potential recall and reporting bias and limits causal inference. Accordingly, the proposed Integrated Assessment Framework should be regarded as an evidence-informed conceptual model rather than a validated decision-support tool. Future cross-sector empirical studies are needed to evaluate its applicability, reliability, and effectiveness before routine implementation in occupational safety and health practice.

## 7. Limitations of the Review

This review has several limitations. As a narrative review, it did not follow a formal systematic review protocol or include quantitative meta-analysis. Although the included studies were qualitatively appraised during evidence synthesis, no standardized risk-of-bias assessment or evidence-grading framework was applied. In addition, the reviewed studies varied considerably in occupational sectors, study designs, sample characteristics, outcome measures, and ergonomic assessment methods, limiting direct comparison across studies and the generalizability of some findings. Publication bias and language bias may also have influenced the available evidence, as only English-language publications were included. Furthermore, the proposed Integrated Assessment Framework represents an evidence-informed conceptual synthesis that has not yet been empirically validated across different industrial settings. Future research should evaluate its applicability, reliability, and effectiveness in diverse occupational environments. Despite these limitations, the review provides a comprehensive synthesis of current evidence and proposes an integrated assessment framework to support ergonomic risk assessment, occupational safety and health practice, and future research.

## CONCLUSIONS

Work-related musculoskeletal disorders remain a significant occupational health issue across industrial sectors, arising from interacting biomechanical, organizational, environmental, and individual factors. This review identifies repetitive movements, forceful exertions, awkward postures, vibration exposure, and prolonged static work as key contributors. The evidence shows that no single method is sufficient to fully assess musculoskeletal risk, as self-reported, observational, and biomechanical approaches provide complementary but incomplete perspectives.

To address this limitation, an Integrated Assessment Framework is proposed, combining these assessment methods to support comprehensive risk identification, intervention planning, and continuous ergonomic improvement. Effective prevention requires a systems-based strategy integrating engineering controls, administrative measures, worker participation, and emerging technologies. Future studies should validate the framework across diverse industrial sectors and evaluate its effectiveness in reducing WMSD burden and improving occupational safety performance. The framework offers a structured foundation for evidence-based assessment and prevention of WMSDs in industrial settings.

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