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# Advanced Perspectives on Ergonomic Risk Assessment: From Classical Techniques to Intelligent Systems

**Maria-Rafaella ȘERB, Gina-Mihaela SICOE, Daniel-Constantin ANGHEL**
National University of Science and Technology POLITEHNICA Bucharest, Pitesti University Centre

Corresponding author e-mail: dc.anghel@upb.ro

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**Abstract.** This article critically reviews the evolution of ergonomic risk assessment methods, examining traditional evaluation techniques alongside recent innovations such as markerless motion capture systems and digital twin integration. It also explores the nature of ergonomic risks in modern industrial environments and highlights best practices and future directions for effective workplace design. The purpose is to offer a pragmatic and forward-looking framework adaptable to Industry 4.0 needs.
**Keywords:** Ergonomics, Risk Assessment, Markerless Motion Capture, Workplace Innovation, Musculoskeletal Disorders, Industry 4.0

## INTRODUCTION

As industries evolve rapidly under the influence of automation and digitalization, ergonomics has gained renewed importance. Defined as the science of optimizing the interaction between people and systems [1], ergonomics now encompasses physical, cognitive, and organizational domains [2].
Despite technological advances, work-related musculoskeletal disorders (WMSDs) persist at high rates, particularly in physically demanding industries [3]. This review discusses how classical ergonomic methods merge with new technologies to provide dynamic solutions adapted to modern challenges.

## LITERATURE REVIEW

### *Classical Ergonomic Assessment Techniques*

Traditional ergonomic assessment methods have been the foundation of workplace safety and design improvements for decades. Techniques such as OWAS, REBA, RULA, and OCRA offer structured approaches to evaluating postural risks, repetitive strain potential, and overall physical workload [4][5][6][7].

- **OWAS (Ovako Working Posture Assessment System):** Developed in the 1970s, OWAS classifies working postures by observing the positions of the back, arms, and legs during tasks. It is widely used for analyzing heavy manual work but has limited sensitivity for finer postural nuances.

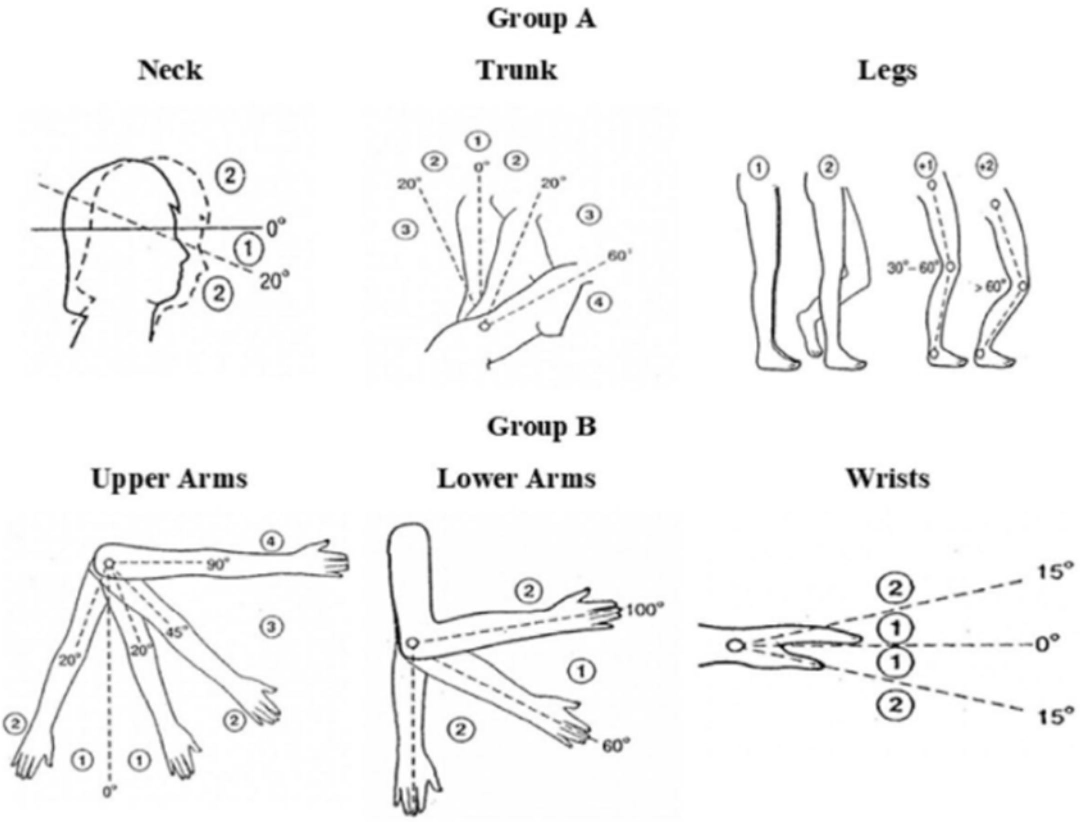


**Figure 1**. Body elements belonging to groups A and B and their corresponding movement angles [8]

- **REBA (Rapid Entire Body Assessment):** Designed to evaluate dynamic tasks, REBA assesses the whole-body posture, coupling joint angles with task variables like force, repetition, and coupling quality. It allows for a broader assessment of risks across various industries.

**Table 1** – REBA action levels [8]

| REBA Action Levels | | | |
|---|---|---|---|
| REBA Value | *Risk Level* | *Action Level* | *Action (After Complementary Action)* |
| 1 | null | 0 | not necessary |
| 2 a 3 | low | 1 | may be necessary |
| 4 a 7 | medium | 2 | necessary |
| 8 a 10 | high | 3 | needed very soon |
| 11 a 15 | very high | 4 | necessary now |

- **RULA (Rapid Upper Limb Assessment):** Focused on upper extremity strain, RULA targets repetitive or static upper limb activities such as those found in assembly line work, evaluating arm, wrist, and neck posture in a scoring framework.

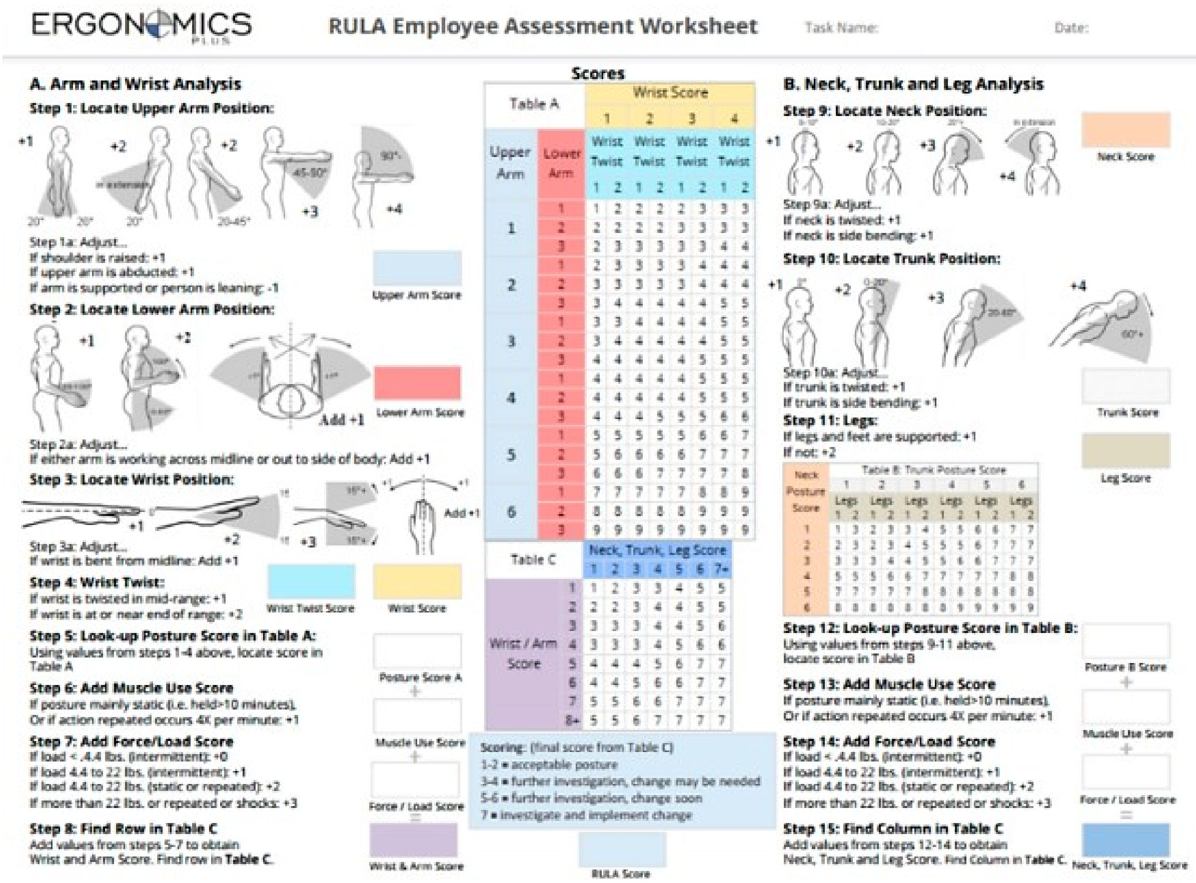


**Figure 2**. RULA Worksheet [9]

- **OCRA (Occupational Repetitive Actions):** This method specifically quantifies repetitive actions involving the arms and shoulders, helping to identify thresholds beyond which the risk of WMSDs sharply increases.

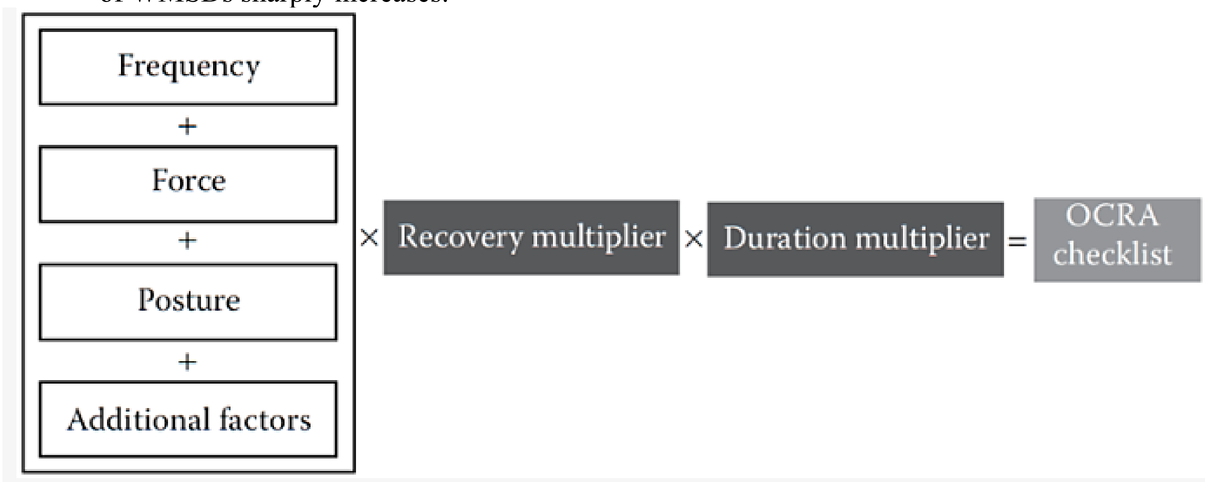


**Figure 3**. Calculation risk factors of the OCRA Checklist method [10]

Despite their utility, traditional methods often require trained evaluators and manual input, introducing subjectivity and limiting their ability to capture real-time or subtle risk factors. Moreover, these approaches generally provide "snapshot" evaluations rather than continuous monitoring throughout a worker's day.

***Digitalization and Markerless Motion Capture***

Recent advances in ergonomics leverage technologies like markerless motion capture (MoCap), artificial intelligence (AI), and digital twins to enhance assessment precision and frequency [11][12][16].

- **Markerless Motion Capture Systems:** Utilizing depth-sensing cameras and computer vision algorithms, these systems track human movement without requiring workers to wear sensors. This allows for natural behavior analysis without restricting or altering workflow patterns. Markerless MoCap enables continuous ergonomic risk monitoring, facilitating early detection of unsafe practices.

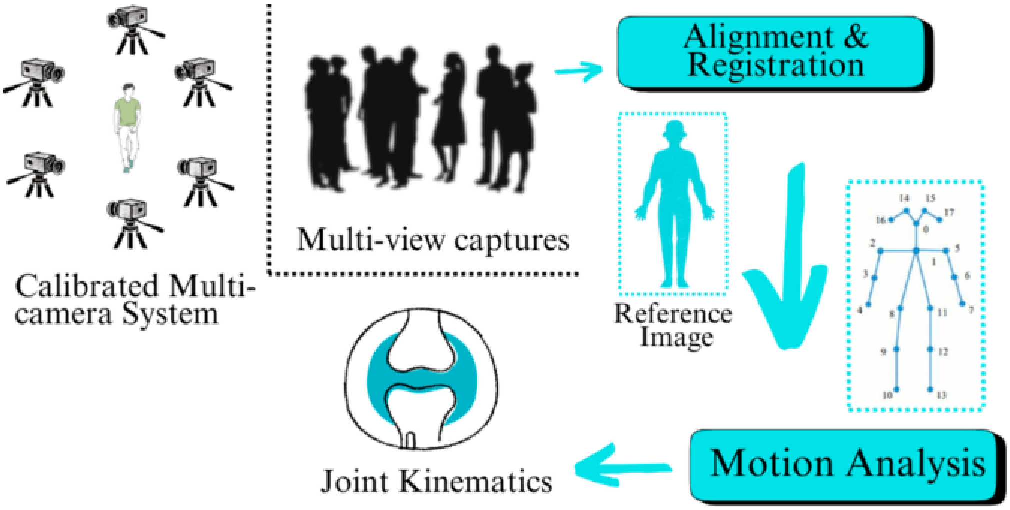


**Figure 4**. A block diagram summarizes the marker-less system for human body pose estimation [18].

- **Integration with Traditional Assessment Models:** Modern systems often combine MoCap data with traditional ergonomic frameworks like REBA and RULA to automatically generate risk scores, thus eliminating human error and bias while providing dynamic feedback [12].

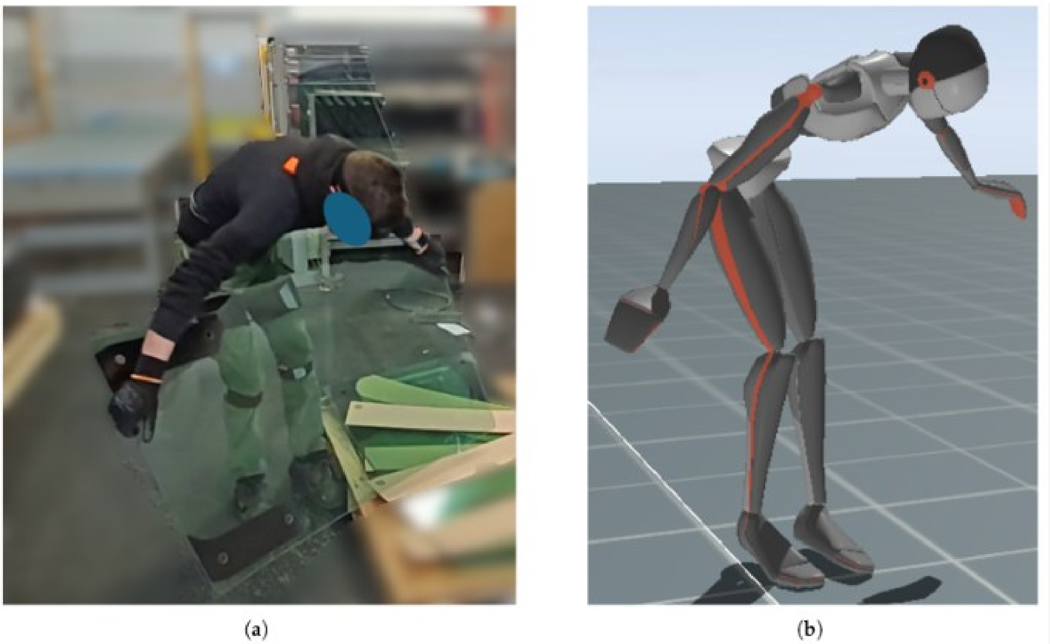


**Figure 5.** Comparison of the real operator and the simulated operator in the Xsens MVN software, version 2024.2.0. (**a**) Operator's movement in the physical workstation activity. (**b**) MoCap's movement on Xsens MVN software [19].

- **Digital Twins:** These virtual representations of real-world environments allow organizations to simulate ergonomic scenarios before physical implementation. By testing workstation designs or production line configurations digitally, companies can predict and mitigate ergonomic risks proactively [16].

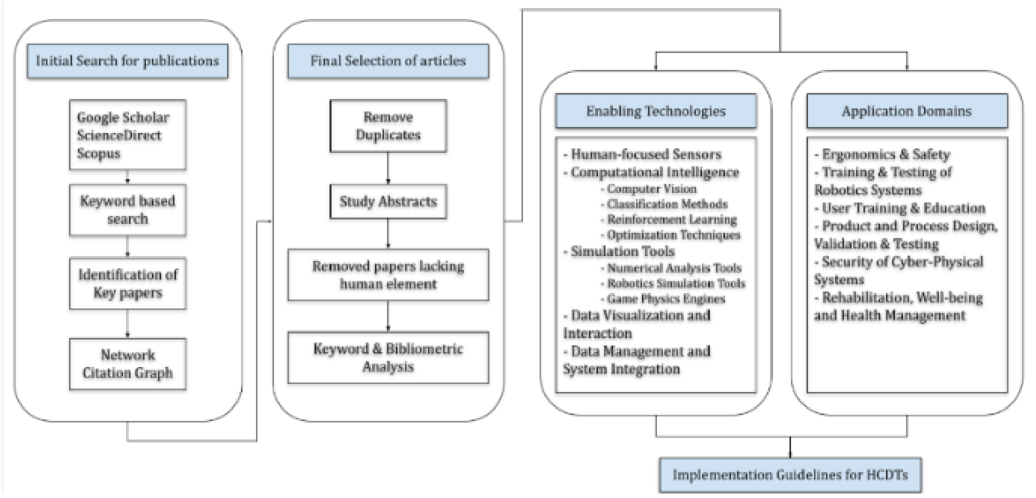


**Figure 6.** Methodology & Structure [20].

While these technologies significantly advance the field, challenges persist. High costs, technical complexity, the need for skilled interpretation, and privacy concerns regarding motion and health data must be addressed before widespread adoption can be achieved.
Nevertheless, digital ergonomics offers transformative potential, enabling ergonomists to shift from reactive to proactive approaches and embedding worker well-being into the core of smart manufacturing strategies.

## SOURCES OF ERGONOMIC RISK IN MODERN INDUSTRY

### *Major Ergonomic Risk Factors*

Ergonomic risks are multifactorial and can stem from physical, organizational, and environmental factors. Understanding these risks is critical to designing effective interventions. The principal ergonomic risk factors include:

- **Static Postures:** Maintaining fixed postures for extended periods restricts blood flow, causes muscle fatigue, and increases the likelihood of musculoskeletal disorders. Occupations involving prolonged sitting or standing, such as assembly line work or clerical jobs, are especially vulnerable [13].
- **Highly Repetitive Movements:** Tasks involving the repetitive use of the same muscle groups, such as packaging, sorting, or data entry, create cumulative stress on tissues, leading to conditions like tendinitis and carpal tunnel syndrome [4].
- **Manual Handling of Loads:** Lifting, carrying, pushing, or pulling heavy loads without adequate mechanical support often results in acute injuries (e.g., sprains) or chronic back disorders. Incorrect lifting techniques amplify these risks significantly [13].
- **Poorly Designed Tools and Workstations:** When tools do not fit the anthropometric characteristics of workers, or when workstations require awkward reaches or postures, the body experiences undue mechanical stress. Poor ergonomics in tool design can escalate minor discomforts into severe injuries.
- **Environmental Stressors:** Noise, vibration, lighting, and temperature extremes contribute indirectly to ergonomic risk by inducing fatigue, distraction, and physical strain. For instance, excessive noise may lead to increased muscle tension, while vibration can exacerbate upper limb disorders [13].

### *Risk Analysis by Process Type*

Industrial sectors present distinctive ergonomic challenges depending on the nature of tasks performed:

- **Manufacturing and Assembly Lines:** Characterized by repetitive tasks performed under time pressure, these environments often force workers into non-neutral postures. Limited task variability and high production quotas compound cumulative trauma disorders [4].

- **Warehousing and Logistics:** Frequent lifting and carrying tasks, often involving large, unwieldy loads, pose high risks for back injuries and joint strain. Moreover, time pressures in order fulfillment contribute to unsafe movement patterns.
- **Office Work:** Although less physically intense, prolonged sedentary behavior, poor workstation setup, and insufficient movement breaks contribute significantly to musculoskeletal complaints, particularly in the neck, shoulders, and lower back regions.
- **Construction and Heavy Industries:** Workers in these fields encounter highly variable environments involving carrying heavy materials, operating vibrating tools, and working in awkward or extreme conditions. These factors collectively elevate ergonomic risk substantially [12].

Each industry requires a tailored ergonomic risk management plan that considers its unique operational context, worker demographics, and technological readiness.
Emerging studies suggest that integrating advanced technologies such as real-time motion tracking and wearable feedback devices can significantly enhance the identification and management of ergonomic risks across diverse industrial domains [11][12].

## BEST PRACTICES AND INNOVATIONS IN ERGONOMIC OPTIMIZATION

### *Technological Enhancements*

Technological innovations play a central role in transforming traditional ergonomic practices. Key advancements include:

- **Augmented Reality (AR):** AR-based systems provide interactive ergonomic training by overlaying digital information onto the physical workspace [14]. Workers can visualize optimal body postures, learn correct lifting techniques, and receive real-time feedback during task execution. Research indicates that AR significantly enhances learning retention and helps correct hazardous behaviors before they become ingrained.
- **Industrial Exoskeletons:** Wearable exoskeletons are increasingly deployed in industries where repetitive or heavy lifting tasks are common [15]. By distributing the mechanical load across the body, exoskeletons reduce muscular fatigue, prevent overexertion injuries, and enhance task endurance. Some designs even offer powered assistance, adapting to the worker's movements dynamically.
- **Digital Twins:** Digital twins simulate worker interactions with machinery, tools, and workflows in virtual environments before implementation [16]. By integrating real-time sensor data, ergonomists can predict the ergonomic impact of a workstation or process change, thus optimizing human-machine interfaces and minimizing potential injury risks.
- **Markerless Motion Capture Systems:** These systems enable detailed biomechanical analysis without physical markers, allowing companies to monitor ergonomic risks across entire production lines continuously [11]. Data collected are used to fine-tune task design and eliminate unsafe motion patterns.

### *Organizational and Procedural Improvements*

Technological solutions must be paired with organizational strategies to maximize ergonomic benefits. Best practices include:

- **Systematic Workstation Redesign:** Utilizing data from ergonomic audits, companies should adjust workstation heights, tool positions, and layout configurations to match human capabilities and limitations.
- **Strategic Job Rotation:** Rotating employees between tasks requiring different physical and cognitive demands prevents overuse of specific muscle groups, reducing the risk of repetitive strain injuries [5].
- **Active Break Implementation:** Scheduled micro-breaks throughout shifts promote muscle recovery and cognitive refreshment, counteracting the adverse effects of static and repetitive work.
- **Ergonomics Committees:** Establishing multidisciplinary teams responsible for continuous ergonomic improvement ensures that employee feedback is incorporated into the design and adjustment of work processes.

- **Lean Manufacturing and Ergonomics Integration:** Combining lean manufacturing principles with ergonomic design optimizes both productivity and worker well-being, reducing waste and enhancing value simultaneously.

### *The Importance of Ergonomics Training*

Training remains a cornerstone of ergonomic optimization. Effective programs should include:

- **Customized Ergonomic Training:** Tailored to specific job roles, highlighting the unique ergonomic risks and best practices relevant to each.
- **Simulation-Based Learning:** Using VR and AR environments to allow workers to experience and respond to realistic ergonomic scenarios.
- **Continuous Feedback Mechanisms:** Real-time feedback from wearable sensors or markerless systems helps workers self-correct postures and movements during actual tasks [17].
- **Cross-Cultural and Multigenerational Training:** Recognizing diversity in workforce age, language, and cultural background ensures that ergonomic practices are effectively communicated and adopted across the organization.

Evidence suggests that organizations with robust ergonomic training programs experience fewer injuries, higher employee satisfaction, and enhanced operational performance.

## CONCLUSIONS AND FUTURE RESEARCH DIRECTIONS

Ergonomics stands at a critical crossroads. While traditional assessment methods—such as REBA, RULA, and OCRA—remain foundational, they are no longer sufficient to address the complexity and pace of modern industrial environments shaped by Industry 4.0. Emerging technologies, including markerless motion capture, digital twins, augmented reality, and exoskeletons, offer significant opportunities to improve ergonomic risk assessments by enabling continuous monitoring, predictive analytics, and more precise interventions. These innovations have the potential to reduce the incidence of work-related musculoskeletal disorders and enhance overall worker well-being.

However, these advances also introduce new challenges: the lack of standardized protocols, high implementation costs, the need for specialized expertise, and the risk of relying solely on automated systems while overlooking subtle human factors—such as facial expressions or spontaneous worker adaptations. A hybrid approach that combines technological tools with expert human observation remains essential for a holistic understanding of ergonomic risks.

Looking forward, future research should focus on:

- Developing AI-powered systems capable of real-time ergonomic risk prediction based on motion patterns and worker behaviors;
- Creating personalized ergonomic profiles using data from wearable devices and sensor systems;
- Establishing open standards and protocols for the use of digital technologies in ergonomics;
- Expanding the role of AR and VR in training and ergonomic assessment;
- Exploring the links between ergonomics, sustainability, and worker mental health.

In conclusion, the future of ergonomics lies in an integrated, human-centered approach—one that seamlessly blends advanced technologies with ergonomic expertise to promote worker health, operational efficiency, and industrial resilience.

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