International Journal of Multidisciplinary Research and Growth Evaluation.

The Need for Ergonomics and Safety in Automated Manufacturing Environments

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Article Info

ISSN (online): 2582-7138
Volume: 06
Issue: 03
May-June 2025
Received: 07-03-2025
Accepted: 08-04-2025
Page No: 300-307

Abstract
The increasing adoption of automation in manufacturing environments has revolutionized production processes, resulting in enhanced efficiency, precision, and scalability. However, the integration of automated systems has also introduced complex ergonomic and safety challenges that demand urgent attention. Traditional safety practices are often inadequate in addressing the dynamic risks associated with human-machine interactions, as poor ergonomic design can lead to musculoskeletal disorders, cognitive overload, and operational inefficiencies. This article examines the critical need for a structured approach to ergonomics and safety in automated manufacturing settings. It emphasizes the importance of designing workstations, interfaces, and workflows that align with human capabilities and limitations. The paper also explores how proactive safety strategies, such as real-time monitoring, collaborative robotics (cobots), and adaptive training programs, can mitigate emerging risks. By synthesizing insights from recent studies and industrial case analysis, the discussion underscores that prioritizing ergonomics and safety not only protects workers, but also optimizes system performance and organizational outcomes. Ultimately, the research advocates for a human-centered design philosophy as a fundamental component in the evolution of safe and sustainable automated manufacturing environments.

Keywords: ergonomics, safety, automation, manufacturing, workplace design, human-machine interaction, occupational health

1. Introduction

The accelerated adoption of automation technologies has profoundly transformed manufacturing operations, driving significant improvements in efficiency, precision, and scalability. Robotics, Artificial Intelligence (AI), and cyber-physical systems have been pivotal in optimizing production processes, reducing human error, and enhancing product quality (Leong, 2022) [12]. AI is a range of technologies that assist computers to achieve different advanced functions, like the ability to perceive, understand, appraise and translate both spoken and written languages, analyze and predict data, make proposals and suggestions, and so much more (Okpala and Okpala, 2024; Okpala *et al*., 2025) [9, 18]. AI-driven strategies optimize maintenance schedules, improve equipment reliability, and reduce downtime, thereby contributing immensely to the competitiveness and sustainability of production processes (Okpala and Udu, 2025; Okpala *et al*., 2023a) [21, 24].

In parallel, innovations such as the Internet of Things (IoT) and predictive analytics have strengthened operational safety and regulatory compliance frameworks (Suhara *et al*., 2024) [29]. By leveraging IoT, manufacturing firms can attain enhanced organization, technological management, agility, as well as customer-centered product and service tailoring (Igbokwe *et al*., 2024; Nwankwo *et al*.,2024) [9, 18]. Despite these advancements, the shift towards automation has introduced new challenges related to workplace safety and ergonomics, particularly as human roles evolve toward supervisory, programming, and maintenance functions. The transition from manual tasks to indirect system interaction necessitates a comprehensive rethinking of ergonomic design principles and safety standards. Emerging evidence highlights that workers are increasingly engaged in tasks involving programming, monitoring, and maintenance rather than direct operational control (Ratushnyi, 2023) [28].

Consequently, there is a pressing need to revise ergonomic guidelines to address the physical and psychological demands of these new roles (Kaur and Sharma, 2025) [11]. Inadequate consideration of human factors may result in ergonomic risks such as musculoskeletal disorders, awkward postures, repetitive movements, cognitive overload, and diminished situational awareness (Godwin and Okpala, 2015). Moreover, workplace injuries and accidents may persist, or even intensify, in highly automated environments if proactive interventions are not implemented (Tsymbal, 2024) [30]. Automation further introduces safety risks linked to interactions with high-speed robotic systems, complex control architectures, and dynamic production environments. Addressing these hazards requires evolving traditional safety frameworks to incorporate real-time ergonomic assessments, collaborative safety systems, and continuous monitoring technologies (Suhara *et al.*, 2024) [29]. This article underscores the imperative of integrating ergonomics and safety within automated manufacturing environments, advocating for strategies such as ergonomic workplace redesign, human-centered system integration, and sustained safety training initiatives. By prioritizing worker well-being alongside technological efficiency, industries can achieve safer, more resilient, and more productive automated systems.

2. The importance of ergonomics in automated environments

The integration of automation in manufacturing has significantly transformed the nature of work, shifting employees' responsibilities from manual tasks to supervisory, programming, and maintenance-oriented roles. This transition necessitates thoughtful ergonomic interventions to ensure that workers can interact with automated systems efficiently and safely. Inadequate ergonomic design may expose workers to awkward postures, repetitive motions, and prolonged static positioning, which can contribute to physical discomfort and long-term health complications.

Mgbemena *et al.*, (2020) [15], observed that workers in manufacturing workstations are often required to undertake manual handling activities which involves lifting, lowering, and carrying. They explained that these workers are prone to human factor errors which are sometimes necessitated by inadequate sleep at night and consequently lead to increased rate of occurrence of accidents in shopfloors. Also, Dimberg *et al*,. (2015) [4], and Okpala and Ihueze (2017) [26], reported that workers often adopt non-neutral positions, leading to increased strain and discomfort. In the rapidly evolving landscape of robotics and AI, the synergy between humans and robots has become increasingly integral to various industries, ranging from manufacturing and healthcare to service and entertainment (Okpala *et al.*, 2023b) [25]. Embedding ergonomic principles into workstation design and human-machine interfaces can therefore minimize physical and cognitive load, enhance comfort, and support smoother role adaptation within automated environments.

A critical consequence of poor ergonomic practices in automated manufacturing is the heightened risk of Musculoskeletal Disorders (MSDs). Despite high levels of automation, repetitive tasks, unsuitable workstation heights, and non-adjustable tools remain prevalent risk factors for conditions such as carpal tunnel syndrome, tendonitis, and lower back pain (Harun *et al.*, 2025) [6]. Integrating ergonomic considerations during the design phase—such as adjustable workstations, ergonomically optimized tools, and task variability—can substantially reduce the incidence of these injuries. Furthermore, ergonomically enhanced environments contribute to greater productivity by minimizing fatigue, reducing errors, and improving task efficiency. Mackey (2024) [14], observed that comfortable work settings significantly enhance worker concentration and motivation, leading to improved output. In a related study, Kamijantono *et al.*, (2024) [10], emphasized that interventions like adjustable workstations and properly designed tools effectively mitigate the risk of MSDs. Similarly, Mishra and Narendra (2020) [16] highlighted that prioritizing ergonomics fosters a healthier work environment, benefiting both employees and organizations. Thus, investing in ergonomic improvements not only protects workers' health, it also strengthens operational performance, thereby positioning ergonomics as a critical component of sustainable success in automated manufacturing systems.

Ergonomic risk factors in automated manufacturing

Ergonomic Risk Factors in Automated Manufacturing provides an overview of common ergonomic hazards found in automated manufacturing environments. Table 1 highlights key risk factors such as repetitive motions, awkward postures, and excessive force, along with their potential effects on worker health, including musculoskeletal disorders and other long-term injuries.

Table 1: Ergonomic risk factors in automated manufacturing

Ergonomic Risk Factor	Description	Potential Impact on Worker Health
Repetitive Motions	Repeating the same task or movement for extended periods (e.g., assembly, packaging).	Increased risk of musculoskeletal disorders, such as tendonitis, carpal tunnel syndrome, and repetitive strain injuries.
Awkward Postures	Positions that involve bending, twisting, or reaching to operate machines or tools.	Strain on the spine, shoulders, and neck; risk of back pain, muscle fatigue, and long-term spinal injuries.
Excessive Force	Tasks that require workers to exert excessive physical force, such as lifting heavy objects or pushing machines.	Increased strain on muscles and joints, leading to acute injuries and long-term joint degeneration (e.g., osteoarthritis).
Vibration Exposure	Prolonged exposure to vibrations from machines or tools.	Damage to nerves, blood vessels, and tissues, causing conditions like hand-arm vibration syndrome (HAVS) and circulation issues.
Static Postures	Maintaining the same posture for prolonged periods, often due to poorly designed workstations.	Increased pressure on muscles and joints, leading to fatigue, discomfort, and MSDs, especially in the lower back and legs.
Poor Workstation Design	Workstations that do not accommodate workers' physical dimensions or tasks (e.g., too high or	Poor alignment of the body, leading to musculoskeletal strain, discomfort, and reduced task efficiency.

	low).	
Repetitive Forceful Tasks	Tasks requiring repetitive application of force, such as gripping or pressing.	Risk of muscle and tendon damage, as well as joint strain, particularly in the hands, wrists, and arms.
Lack of Recovery Time	Insufficient breaks or recovery periods between tasks or shifts.	Increased fatigue, risk of overexertion, and development of chronic conditions like tendinitis or lower back pain.
Environmental Factors	Poor lighting, noise, temperature extremes, or poor air quality that interfere with task performance.	Increased fatigue, eye strain, headaches, and discomfort, which can indirectly affect posture and task performance

Ergonomic risk factors in automated manufacturing identifies critical ergonomic hazards inherent in automated manufacturing environments. These risk factors, including repetitive motions, awkward postures, excessive force, and vibration exposure, pose significant threats to worker health and well-being. Repetitive tasks and the application of excessive force can lead to MSDs, like tendonitis and carpal tunnel syndrome, by placing undue strain on muscles and joints. Awkward postures, involving bending, twisting, or reaching, create stress on the spine, neck, and shoulders, increasing the risk of chronic spinal injuries. Additionally, static postures and poorly designed workstations exacerbate discomfort, fatigue, and physical strain, further compromising worker health. Vibration exposure, combined with insufficient recovery time, increases the likelihood of nerve and tissue damage, contributing to long-term health issues. Effectively addressing these ergonomic risks is essential to mitigate injury risks and foster a safer, more productive working environment.

3. Safety concerns in automated manufacturing

The integration of automation into manufacturing processes has introduced a new spectrum of safety challenges that necessitate proactive and comprehensive management strategies. A primary concern lies in human-machine interaction, where unintended or unexpected movements of robotic systems present significant risks to workers (Beauchamp *et al*., 1989). In the absence of appropriate safeguards such as physical barriers, sensor-based monitoring, and emergency stop functionalities the likelihood of collisions or entrapments increases markedly. As the prevalence of collaborative robots (cobots) and high-speed automated machinery grows, it becomes imperative to design systems that embed predictive safety technologies and incorporate fail-safe mechanisms to safeguard human operators.

Equally critical is the issue of cognitive overload within automated manufacturing environments. The supervision of complex, automated systems require operators to process vast amounts of real-time information, heightening cognitive demands and increasing the potential for lapses in attention and delayed responses (Lombardi *et al*., 2022) [13]. Moreover, the monotony associated with repetitive tasks may diminish vigilance over time. To address these challenges, the development of intuitive Human-Machine Interfaces (HMIs) that streamline information flow and support efficient decision-making is essential. Complementarily, continuous training programs aimed at enhancing workers' familiarity with automation technologies are vital in mitigating cognitive strain and fostering heightened situational awareness.

Furthermore, the establishment of specialized emergency protocols tailored to highly automated environments is indispensable. Conventional emergency procedures, designed for manual operations, may prove inadequate when confronting the dynamic behaviors of automated systems. Heinold *et al*., (2023) [7], and Neu *et al*., (2018) [17], advocated for automation designs that account for workers' physical and cognitive capacities, including the integration of brain-computer interfaces to monitor cognitive states and enable real-time system adjustments. Consequently, the implementation of emergency frameworks incorporating real-time alerts, automatic system shutdowns, and structured evacuation strategies is critical to ensuring the safety of personnel and the protection of equipment in modern automated manufacturing settings.

Injury frequency in automated vs. non-automated manufacturing

Injury frequency in automated vs. non-automated manufacturing visually compares workplace injury frequencies between automated and traditional manual manufacturing processes. Figure 1 highlights how automation influences safety outcomes, showcasing the potential for reduced injury rates in environments with well-integrated automation, as compared to manual operations.

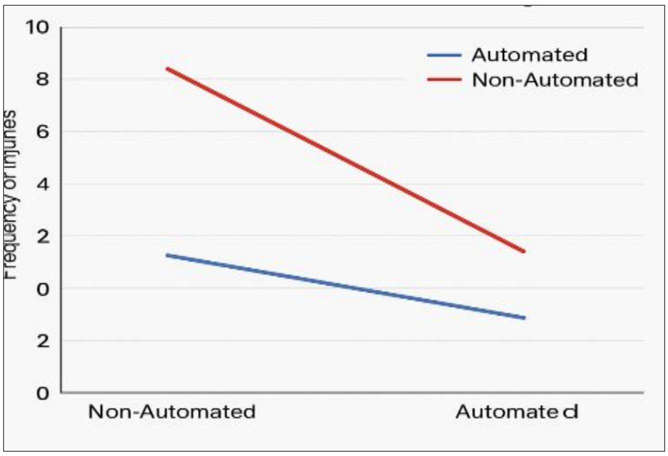

Fig 1: Comparison of injury frequency between automated and non-automated manufacturing environments

The line chart in the figure indicates a clear trend: automated manufacturing tends to have a significantly lower frequency of workplace injuries compared to traditional manual processes. This highlights the positive impact of automation on safety, as automation can reduce human error, eliminate exposure to hazardous tasks, and enhance overall operational efficiency. Scholarly literature supports this, with studies indicating that automation reduces the risk of physical injuries by minimizing manual handling and repetitive motion (Nur *et al.*, 2023) [19]. Additionally, automated systems often incorporate safety features such as sensors and fail-safes, which further mitigate risk.

4. Strategies for enhancing ergonomics and safety

The integration of automation into manufacturing environments necessitates deliberate strategies that prioritize both ergonomics and safety. A critical approach involves the application of human-centered design principles, wherein automation systems are tailored to meet the physical and cognitive needs of workers. This includes the development of intuitive interfaces, accessible controls, and adjustable workspaces designed to accommodate a diverse workforce. Cardenas (2023) [3], underscores that ergonomic workplaces not only reduce injury rates but also enhance productivity by aligning environmental design with worker needs. Emphasizing ergonomics during the design phase reduces the risk of musculoskeletal injuries and cognitive overload, thereby fostering safer and more efficient operational environments.

The strategies for the enhancement of ergonomics and safety in automated manufacturing environments are highlighted in table 2. In workstation design, adjustable workstations are made to enable machine operators to change the angle or height for standing or sitting tasks for strain reduction. Also, ergonomic tool placement reduces awkward postures by ensuring that tools and controls are positioned within easy reach.

Table 2: Strategies to enhance ergonomics and safety in automated manufacturing

Category	Strategy	Description
Workstation Design	Adjustable Workstations	Allow operators to adjust height/angle for standing or sitting tasks to minimize strain.
	Ergonomic Tool Placement	Tools and controls positioned within easy reach to reduce awkward postures.
Automation and Robotics	Collaborative Robots (Cobots)	Designed to safely work alongside humans, reducing manual handling and strain.
	Automated Material Handling	Use of conveyors, AGVs, and robotic arms to reduce lifting and repetitive motion injuries.
Environmental Control	Lighting and Noise Control	Adequate lighting and noise insulation reduce fatigue and enhance concentration.
	Climate Control	Maintain optimal temperature and ventilation to support worker comfort and safety.
Human-Machine Interfaces	Intuitive Interface Design	Clear, user-friendly screens and controls reduce cognitive load and error.
	Visual and Audio Alerts	Enhance situational awareness using standardized warnings and alerts.
Training and Protocols	Ergonomics and Safety Training	Regular training to recognize risks, use assistive tech, and follow safety practices.
	Emergency Procedures and E-Stop Training	Ensure all personnel know how to react in case of mechanical or electrical failures.
Monitoring and Feedback	Real-Time Ergonomic Monitoring	Sensors and AI to analyze posture, repetition, and load on operators.
	Incident Reporting Systems	Easy-to-use platforms to report near-misses or hazards for timely improvements.
Maintenance and Upkeep	Predictive Maintenance of Equipment	Prevent mechanical failures that could cause injuries.
	Regular Ergonomic Audits	Ongoing assessments to ensure continuous improvement in ergonomic design.

Moreover, systematic risk assessments constitute an essential component of safety integration. Regular ergonomic and safety evaluations facilitate the early identification of potential hazards, enabling organizations to implement preventive measures proactively. Dynamic risk assessment models responsive to system changes and human feedback have demonstrated particular effectiveness in complex automated settings. In addition, the advent of wearable technologies offers real-time monitoring of critical worker health metrics, such as posture, fatigue, and exertion levels (Hilmi *et al.*, 2024) [8]. These technologies provide immediate feedback, allowing for timely adjustments that optimize ergonomics and mitigate injury risks.

Training and education represent further indispensable elements. As automation systems grow increasingly sophisticated, comprehensive and continuous training programs are necessary to ensure that workers are equipped to interact safely with these technologies and to identify emerging risks (Armstrong *et al.*, 2024) [1]. Effective training extends beyond operational knowledge to encompass situational awareness, emergency protocols, and ergonomic best practices. Finally, the deployment of collaborative robotics (cobots) has significantly advanced human-robot interactions.

Okpala *et al.*, (2023b) [25], explained that the success of human-robot collaborations hinges on the design of Human Robot Interactions (HRIs) that prioritize user experience, safety, as well as efficiency, as ergonomics and human factors principles play a crucial role in achieving these objectives, by tailoring interfaces to human capabilities, preferences, and limitations. Unlike traditional industrial robots, cobots integrate safety features such as force limitations and proximity sensors, enabling them to operate safely alongside human workers (Heinold *et al*., 2023) [7]. Consequently, cobots enhance operational efficiency while simultaneously reducing risks inherent to automated systems.

5. Benefits of prioritizing ergonomics and safety

Investments in ergonomics and safety within automated manufacturing environments offer substantial benefits for both organizations and their workforce. A primary advantage is the marked reduction in workplace injuries and illnesses. The integration of ergonomic interventions and safety measures, specifically tailored to the unique demands of automation, effectively minimizes the risk of MSDs, machinery-related accidents, and other occupational hazards. Rah and Park (2005) [7], asserted that ergonomic interventions are critical in reducing risk factors associated with MSDs, particularly in settings characterized by repetitive tasks. Similarly, Odebiyi and Okafor (2023) [20], emphasized that the application of effective ergonomic principles, which consider workers' physical capabilities, significantly decreases the incidence of Work-related Musculoskeletal Disorders (WMSDs). These improvements not only protect the workers' health, but also reduce operational disruptions, compensation claims, and healthcare costs, thus enhancing overall organizational efficiency.

Beyond injury prevention, prioritizing ergonomics and safety positively influences employee morale and organizational culture. Ratushnyi (2023) [28], emphasized that workers in ergonomically optimized environments report higher job satisfaction, motivation, and engagement, all of which contribute to increased productivity and retention key factors in high-skill automated industries. Moreover, adherence to occupational health and safety standards, such as ISO 45001, not only ensures regulatory compliance but also reinforces an organization's reputation for corporate responsibility and commitment to worker welfare (Odebiyi and Okafor, 2023) [20]. ISO 45001, which is a global standard that was presented by the International Organization for Standardization, provides a structured framework for the identification of risks, safety performance enhancement, as well as enhancement of continuous improvement in safety culture (Udu and Okpala, 2025b) [22].

Incidence of musculoskeletal disorders (MSDs) in automated manufacturing

Incidence of Musculoskeletal Disorders (MSDs) in automated manufacturing illustrates the trends in MSD occurrence before and after the implementation of ergonomic interventions. Figure 2 highlights the effectiveness of targeted ergonomic strategies in reducing injury rates, emphasizing the critical role of proactive measures in safeguarding workers' health and productivity.

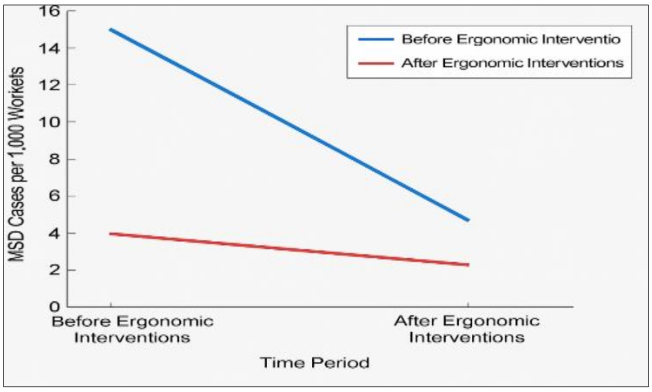

Fig 2: Incidence of Musculoskeletal Disorders (MSDs) in Automated Manufacturing

The figure presents the incidence rates of MSDs in automated manufacturing environments, comparing data before and after the implementation of ergonomic interventions. The trend shows a noticeable decline in MSD cases following ergonomic improvements, such as the redesign of workstations, use of assistive robotic arms, and adjustments to equipment height and reach. According to Kamijantono *et al*., (2024) [10], poor ergonomics is a major contributor to MSDs in industrial settings, even in automated systems. By integrating ergonomic principles, manufacturers effectively reduce physical strain on workers, enhancing comfort and productivity. Godwin and Okpala (2013) [5], confirmed that ergonomic interventions significantly reduce the risk of MSDs.

6. Challenges in Implementation

While the advantages of prioritizing ergonomics and safety in automated manufacturing environments are widely recognized, several barriers continue to impede effective implementation. A primary challenge is the substantial initial investment required to design and integrate ergonomic solutions and comprehensive safety systems. For many organizations, particularly SMEs, these upfront costs are often prohibitive, despite evidence demonstrating significant long-term savings through injury prevention and productivity gains (Ratushnyi, 2023) [28]. Costs associated with system redesign, acquisition of advanced safety technologies, and the provision of specialized training frequently delay or deter adoption.

Organizational resistance to change further exacerbates implementation challenges. Both management and workers may perceive the introduction of ergonomic and safety initiatives as unsettling to already established workflows, thereby argue over their efficiency. Overcoming such resistance necessitates robust change management frameworks, emphasizing transparent communication of benefits, participatory decision-making and phased implementation strategies.

Moreover, integrating ergonomics and safety features into existing automated systems presents significant technical complexities. Retrofitting legacy equipment, reconfiguring workspaces for human-centered design and ensuring interoperability with advanced safety controls require specialized expertise and careful planning (Kim *et al*., 2023). Addressing these multifaceted challenges is critical to achieving sustainable improvements in workplace safety and operational performance.

7. The Future of ergonomics and safety in automated manufacturing environments

The future of ergonomics and safety within automated manufacturing environments will be increasingly shaped by technological innovation and the adoption of human-centered design philosophies. Central to this evolution is the integration of AI, the IoT, and sustainable manufacturing practices. AI is poised to transform workplace safety through predictive analytics. By leveraging real-time data captured from embedded sensors and visual monitoring systems, AI can identify subtle patterns associated with ergonomic hazards, enabling early interventions and continuous ergonomic optimization (Ratushnyi, 2023) [28]. Unlike traditional reactive approaches, AI-driven systems provide dynamic feedback and actionable recommendations, ensuring that safety protocols adapt to evolving operational contexts. Furthermore, the incorporation of machine learning algorithms allows these systems to refine their predictive capabilities over time, resulting in increasingly resilient safety infrastructures.

In parallel, the rise of smart factories, enabled by IoT technologies, is expected to significantly enhance real-time monitoring of environmental and ergonomic conditions. IoT devices can also monitor temperature, quality of air, noise level, as well as vibration, ensuring that they are regulated within the best limit for optimal performance and safety. Additionally, IoT-enabled ergonomic assessments, including the tracking of workers' postures and repetitive motions, will facilitate proactive interventions, thereby reducing the incidence of musculoskeletal disorders and related occupational injuries.

Sustainability considerations will also become integral to ergonomic and safety strategies. Future manufacturing systems will prioritize not only environmental stewardship through the use of eco-friendly materials and energy-efficient processes, but also the holistic well-being of workers (Kim *et al*., 2023). This shift acknowledges the interdependence between environmental health, mental wellness, and ergonomic safety. Emerging models will emphasize the reduction of both physical strain and psychological stress, aligning with broader organizational objectives around worker engagement, retention, and productivity.

In conclusion, the convergence of AI, IoT, and sustainable practices represents a critical trajectory for advancing ergonomics and safety within automated manufacturing. By strategically integrating these technologies, organizations can foster safer, healthier, and more adaptive workplaces that balance operational efficiency with workforce well-being. As automation continues to expand, embedding human-centered approaches will not only mitigate risks, but also contribute to sustainable competitive advantage.

8. Conclusion

The effective integration of ergonomics and safety in automated manufacturing environments is essential for ensuring worker protection, while enhancing overall operational efficiency. As manufacturing processes increasingly rely on automation, the adoption of human-centered design principles becomes critical. Human-centered design focuses on creating shopfloors and jobs that align with human abilities and limitations, thereby ensuring a seamless interaction between the workers and machines.

Continuous training programs are fundamental to equipping workers with the skills necessary to navigate automated systems safely. As automation technologies become more sophisticated, ongoing education is required to ensure that workers remain adept at identifying and addressing potential hazards. Moreover, the integration of cutting-edge technologies such as AI, the IoT, and smart sensors is revolutionizing real-time hazard detection. These technologies provide immediate feedback, allowing workers to make timely ergonomic adjustments and prevent injuries (Kim *et al*., 2023).

While automation presents numerous benefits, it also introduces challenges, such as the potential for increased physical and psychological strain on workers. However, these challenges can be mitigated through comprehensive ergonomic solutions and a commitment to the workers well-being. In conclusion, addressing ergonomics and safety in automated environments enables organizations to optimize automation while prioritizing the health and safety of their workforce, ensuring both operational success and a supportive work culture.

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