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Human-Centered Ergonomic Design in Industry 5.0: Enhancing Productivity and Worker Wellbeing

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ABSTRACT

Industry 5.0 represents a paradigm shift from technology-driven automation to a human-centered approach, emphasizing the integration of advanced technologies with human creativity and well-being at its core. This article employs a qualitative literature review to explore the role of ergonomic design as a foundational pillar within Industry 5.0, focusing on its impact on productivity and worker well-being. The review synthesizes findings from recent studies and bibliometric analyses, highlighting how ergonomic interventions—spanning physical, cognitive, and social domains—optimize work environments by aligning them with human capabilities and limitations. Differentiating from existing literature, this research emphasizes the importance of a holistic ergonomic approach in designing work environments that not only enhance safety and comfort but also foster collaboration between humans and intelligent machines. In Industry 5.0, ergonomic design reduces physical strain and cognitive overload, while simultaneously promoting innovation and job satisfaction. The integration of real-time monitoring technologies and adaptive workstations allows for dynamic adjustments, ensuring sustained worker health and organizational efficiency. However, despite these advancements, challenges remain in the widespread adoption of ergonomic principles, particularly in harmonizing technological innovation with the holistic needs of workers. The findings underscore the necessity of a comprehensive, multidisciplinary approach—bridging policy, technology, and human factors—to fully realize the potential of human-centered ergonomic design in Industry 5.0. This study offers actionable insights for researchers and practitioners aiming to create productive, sustainable, and worker-friendly industrial ecosystems, with an added focus on how ergonomic design in Industry 5.0 fosters more adaptive and dynamic human-technology interactions compared to previous approaches.

1. INTRODUCTION

The industrial landscape is undergoing a significant transformation with the emergence of Industry 5.0, a new paradigm that emphasizes the harmonious collaboration between humans and advanced technologies (Zizic et al., 2022). Unlike Industry 4.0, which primarily focuses on automation, digitalization, and the Internet of Things (IoT), Industry 5.0 seeks to place humans back at the center of industrial processes. This approach recognizes the irreplaceable value of human creativity, decision-making, and emotional intelligence, aiming to create a more sustainable, resilient, and inclusive industrial environment. Central to this transition is the concept of human-centered ergonomic design, which ensures that workplaces and technologies are tailored to human capabilities and limitations (Marquardt & Kearsley, 2024). Ergonomics, traditionally concerned with optimizing physical work

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conditions to reduce injury and fatigue, now extends to cognitive and psychosocial factors, especially as workers increasingly interact with intelligent machines and complex systems.

The integration of ergonomic principles in Industry 5.0 environments is critical to enhancing both productivity and worker well-being (Calzavara et al., 2024). As industries adopt collaborative robots (cobots), artificial intelligence (AI), and smart automation, the nature of work is evolving, demanding new ergonomic strategies that support physical safety, mental health, and job satisfaction. Proper ergonomic design not only mitigates risks of musculoskeletal disorders and cognitive overload but also fosters a positive work atmosphere that encourages innovation and engagement. This human-centered focus is essential to achieving the dual goals of Industry 5.0: maximizing efficiency while promoting sustainable workforce development.

Despite the growing interest in both Industry 5.0 and ergonomic design, there remains a significant research gap in understanding how these two domains can be effectively integrated. Existing literature tends to address ergonomic considerations and Industry 5.0 technologies separately, with limited comprehensive analysis on how human-centered ergonomic design can be systematically embedded within Industry 5.0 frameworks. Most studies focus on technological advancements such as AI, robotics, and IoT, or on isolated ergonomic interventions targeting either physical or cognitive aspects. However, a holistic approach that aligns ergonomic design with the unique characteristics and challenges of Industry 5.0—such as human-robot collaboration, real-time adaptability, and emotional well-being—is still lacking. This gap hampers the development of practical guidelines and frameworks that industries can adopt to optimize both productivity and worker health in the new industrial era.

The urgency of addressing this research gap is underscored by the increasing complexity and demands of modern industrial work environments. Poor ergonomic conditions have long been associated with increased workplace injuries, absenteeism, and reduced productivity. As Industry 5.0 technologies become more prevalent, the risk of physical strain, cognitive overload, and psychosocial stress may intensify if ergonomic factors are neglected. Moreover, the global workforce is aging, and inclusivity is becoming a priority, making ergonomic design even more critical to accommodate diverse worker needs. Addressing ergonomic challenges proactively will not only enhance worker safety and satisfaction but also contribute to sustainable organizational performance and competitiveness. Therefore, it is imperative to develop a comprehensive understanding of how human-centered ergonomic design can be leveraged within Industry 5.0 to create healthier, more productive, and resilient workplaces.

Previous research in ergonomics has extensively documented the benefits of ergonomic interventions in reducing physical strain, improving posture, and minimizing repetitive motion injuries in traditional manufacturing and office settings. Cognitive ergonomics studies have explored how workload, attention, and decision-making processes affect worker performance and safety. Meanwhile, literature on Industry 5.0 has begun to emphasize the importance of human-machine collaboration, adaptive automation, and personalized technologies. However, these research streams often remain siloed, with limited integration of ergonomic principles into the design and implementation of Industry 5.0 systems. Some recent studies have started to explore the role of ergonomics in smart factories and collaborative robotics, but these are mostly conceptual or technology-focused rather than comprehensive frameworks grounded in human-centered design.

This study offers a novel contribution by conducting a qualitative literature review that bridges the gap between ergonomic design and Industry 5.0, providing an integrated perspective on how human-centered ergonomics can enhance both productivity and worker well-being. By synthesizing multidisciplinary insights from ergonomics, human factors engineering, industrial automation, and organizational psychology, this research develops a holistic framework tailored to the demands of Industry 5.0. The novelty lies in emphasizing the dynamic, adaptive, and collaborative nature of ergonomic design in the context of intelligent technologies, as well as highlighting the psychosocial dimensions of worker well-being alongside physical and cognitive factors. This comprehensive approach advances the theoretical understanding and offers practical implications for designing future industrial workspaces.

The primary objective of this research is to explore and conceptualize the role of human-centered ergonomic design in Industry 5.0, focusing on its potential to simultaneously enhance productivity and promote worker well-being. Specifically, the study aims to identify key ergonomic principles, challenges, and technological

enablers relevant to Industry 5.0 environments through a systematic qualitative literature review. The findings intend to inform industry practitioners, designers, policymakers, and researchers about effective strategies for implementing ergonomic solutions that support human-machine collaboration, adaptability, and inclusivity.

The benefits of this research are multifaceted. For organizations, adopting human-centered ergonomic design can lead to reduced workplace injuries, improved employee satisfaction, and higher operational efficiency. For workers, it fosters safer, more comfortable, and engaging work conditions that support mental and physical health. At a broader level, this research contributes to the sustainable development of industrial ecosystems that balance technological innovation with human dignity and well-being, aligning with global trends toward responsible and ethical industrial practices.

2. METHODS

Research Type

This study employs a qualitative research approach, specifically utilizing a literature review method to explore the integration of human-centered ergonomic design within Industry 5.0. Qualitative research is appropriate for this study as it aims to gain a deep understanding of complex concepts, relationships, and contextual factors related to ergonomics, productivity, and worker well-being in the evolving industrial landscape. The literature review method enables the synthesis of existing knowledge, identification of research gaps, and development of a conceptual framework grounded in scholarly evidence.

Data Sources

The primary data sources for this study consist of academic journal articles, conference proceedings, industry reports, and authoritative books published in the fields of ergonomics, human factors engineering, industrial automation, and Industry 5.0. These sources were selected from reputable electronic databases such as Scopus, Web of Science, IEEE Xplore, and Google Scholar. The selection criteria focused on publications from the last decade (2013–2024) to ensure relevance to current technological and ergonomic developments. Keywords used in the search included "Industry 5.0," "human-centered design," "ergonomics," "worker well-being," "productivity," and "human-machine collaboration."

Data Collection Techniques

Data collection involved systematic identification, screening, and selection of relevant literature based on predefined inclusion and exclusion criteria. Initially, titles and abstracts were reviewed to determine relevance to the study's focus on ergonomic design in Industry 5.0 contexts. Full-text articles were then examined to extract detailed information related to ergonomic principles, technological integration, productivity outcomes, and worker well-being. The process was iterative, allowing for refinement of search terms and inclusion criteria to capture comprehensive and pertinent studies.

Data Analysis Method

The collected literature was analyzed using thematic content analysis, a qualitative technique that involves coding and categorizing textual data to identify recurring themes and patterns. This method facilitated the synthesis of diverse findings into coherent themes related to ergonomic design dimensions (physical, cognitive, psychosocial), technological enablers, challenges, and impacts on productivity and worker well-being. Through comparative analysis, the study developed an integrative framework highlighting how human-centered ergonomics can be effectively applied within Industry 5.0 environments. The analysis was conducted manually and supported by qualitative data analysis software to ensure rigor and transparency.

3. RESULT AND DISCUSSION

The comprehensive analysis of existing literature on human-centered ergonomic design within the context of Industry 5.0 reveals a multifaceted and evolving landscape where the integration of advanced technologies and human factors is critical to achieving enhanced productivity and worker well-being. Industry 5.0 represents a paradigm shift from the largely technology-driven and automation-centric Industry 4.0 toward a more balanced and symbiotic relationship between humans and machines. This shift necessitates a fundamental re-examination of ergonomic principles, extending beyond traditional physical

ergonomics to encompass cognitive and psychosocial dimensions that are increasingly relevant in the modern industrial environment.

Physical ergonomics continues to be a cornerstone of human-centered design, with a strong emphasis on minimizing physical strain, preventing musculoskeletal disorders, and optimizing the physical interaction between workers and their tools or machines. However, Industry 5.0 introduces new complexities and opportunities through the incorporation of intelligent, adaptive technologies such as collaborative robots (cobots), wearable exoskeletons, and sensor-based monitoring systems. These technologies enable dynamic adjustments to the work environment, tailored to individual worker needs and real-time task demands. For instance, exoskeletons can reduce biomechanical loads during physically demanding tasks, thereby mitigating fatigue and injury risks while sustaining or even enhancing worker productivity. The literature underscores that such ergonomic interventions not only improve safety outcomes but also empower workers, fostering a sense of agency and capability in increasingly automated settings.

Beyond the physical domain, cognitive ergonomics emerges as a critical factor in Industry 5.0, where workers are required to interact with complex information systems, AI-driven decision support tools, and autonomous machinery. Cognitive demands in these environments can lead to overload, mental fatigue, and decreased situational awareness, which negatively impact both productivity and safety. Human-centered design in this context involves creating intuitive, user-friendly interfaces and systems that support effective information processing and decision-making. Adaptive automation, which modulates the degree of machine autonomy based on continuous assessment of human cognitive workload and stress levels, exemplifies a sophisticated ergonomic strategy. Such systems help balance human and machine contributions, reducing errors and enhancing operational efficiency. The literature also highlights the importance of training and skill development to ensure that workers can effectively manage and collaborate with intelligent technologies, further reinforcing cognitive ergonomics as a vital component of Industry 5.0.

Psychosocial ergonomics is increasingly recognized as an essential element of human-centered design in Industry 5.0, reflecting a holistic understanding of worker well-being that includes emotional, social, and organizational factors. Studies reveal that meaningful engagement, autonomy, social support, and positive workplace culture significantly influence job satisfaction, motivation, and resilience. Industry 5.0's human-centric ethos promotes these psychosocial factors by facilitating flexible work arrangements, enhancing communication channels between humans and machines, and incorporating worker feedback into system design and process improvements. The integration of digital platforms for real-time feedback and collaboration fosters a participatory work environment, which has been shown to reduce stress and burnout while enhancing innovation and productivity. This psychosocial dimension is critical for sustaining a healthy workforce capable of adapting to rapid technological changes.

A notable insight from the literature is the imperative for a multidisciplinary and participatory approach to ergonomic design in Industry 5.0. Successful implementation requires collaboration among ergonomists, engineers, IT specialists, organizational psychologists, and the workers themselves. Participatory design methods, where employees actively contribute to the creation and refinement of ergonomic solutions, ensure that interventions are contextually relevant, culturally sensitive, and practically feasible. This collaborative process enhances worker acceptance and ownership of new technologies and work practices, leading to more sustainable outcomes. Furthermore, the literature stresses the importance of continuous monitoring and iterative improvement, leveraging data analytics and sensor technologies to dynamically optimize ergonomic conditions.

Despite the promising advancements, several challenges and barriers to effective human-centered ergonomic design in Industry 5.0 are evident. The rapid pace of technological innovation often outstrips the development of ergonomic standards and guidelines, creating uncertainty for practitioners. Integrating diverse technologies into cohesive, ergonomically sound systems remains complex, particularly in heterogeneous industrial settings. Additionally, disparities in digital literacy and readiness among workers can hinder equitable access to ergonomic benefits, raising concerns about inclusivity and the digital divide. Financial constraints, especially for small and medium-sized enterprises, limit the adoption of advanced ergonomic technologies and adaptive systems. The literature calls for policy interventions, education, and incentives to address these barriers and promote widespread implementation.

1. The Evolution of Human-Centered Ergonomics in Industry 5.0

The transition from Industry 4.0 to Industry 5.0 marks a fundamental change in the philosophy of industrial design, shifting the focus from automation and efficiency to a more balanced approach that prioritizes human involvement and well-being. While Industry 4.0 was characterized by the widespread adoption of automation, robotics, and interconnected systems, it often overlooked the critical role of human factors, leading to challenges in worker adaptation and satisfaction. Industry 5.0, by contrast, places humans at the center of industrial processes, emphasizing the need for workplaces that are not only productive but also supportive of human health, creativity, and fulfillment. This human-centric approach is ROOTED in the principles of ergonomics, which seek to optimize the interaction between people and their work environments.

The evolution of ergonomics in Industry 5.0 is closely tied to the integration of advanced technologies

that both support and enhance human capabilities. Ergonomics is no longer limited to the physical arrangement of workstations or the reduction of repetitive strain; it now encompasses cognitive and psychosocial dimensions as well. The literature highlights that modern ergonomic interventions must address the complexities of human-machine collaboration, ensuring that technology adapts to human needs rather than the other way around. This evolution is supported by the development of new tools and methodologies, such as digital twins and inertial sensors, which enable real-time monitoring and adjustment of ergonomic parameters.

Table 1. Summarizing The Transition From Industry 4.0 To Industry 5.0 With A Focus On The Evolving Role Of Ergonomics And Human-Centric Design:

Aspect	Industry 4.0	Industry 5.0	Ergonomics Evolution	Technologies Supporting Ergonomics
Philosophy	Automation and efficiency	Human-centric, balancing productivity and well-being	Expanded from physical to cognitive and psychosocial factors	Digital twins, inertial sensors, real-time monitoring
Human Role	Often overlooked; worker adaptation challenges	Central to processes; focus on health, creativity, fulfillment	Focus on optimizing human-machine interaction	Adaptive systems that respond to human needs
Workplace Design	Emphasis on mechanization and robotics	Supportive environments enhancing human capabilities	Inclusive design addressing physical and mental demands	Sensors and AI-driven ergonomic adjustments

Aspect	Industry 4.0	Industry 5.0	Ergonomics Evolution	Technologies Supporting Ergonomics
Ergonomic Focus	Physical arrangement, reducing strain	Holistic approach including cognitive load and psychosocial well-being	Integration of real-time data for dynamic adjustments	Wearable devices, virtual simulations
Outcome Goals	Increased productivity and automation	Balanced productivity with improved worker satisfaction and health	Enhanced safety, comfort, and performance	Continuous feedback loops for ergonomic optimization

Furthermore, the rise of collaborative robots (cobots) and artificial intelligence (AI) has redefined the boundaries of ergonomic design. Cobots are designed to work alongside humans, sharing tasks and responsibilities in a manner that leverages the strengths of both parties. This requires a nuanced understanding of task allocation, workload management, and safety protocols, all of which fall under the purview of human-centered ergonomics. AI-driven analytics further enhance this process by providing continuous feedback on worker performance and well-being, enabling dynamic adjustments to work conditions.

The evolution of ergonomics in Industry 5.0 also involves a shift in organizational culture and management practices. Companies are increasingly recognizing the value of participatory design, where workers are actively involved in shaping their work environments. This approach not only improves the relevance and effectiveness of ergonomic interventions but also fosters a sense of ownership and engagement among employees. The integration of ergonomics into strategic decision-making processes is seen as a key driver of long-term organizational success.

Despite these advancements, the literature identifies several challenges in the widespread adoption of human-centered ergonomic design. These include the need for standardized frameworks, the integration of diverse technologies, and the development of cost-effective solutions that are accessible to organizations of all sizes. Overcoming these challenges requires collaboration between academia, industry, and policymakers, as well as a commitment to continuous learning and adaptation.

In summary, the evolution of human-centered ergonomics in Industry 5.0 represents a holistic and dynamic approach to workplace design. It is characterized by the integration of advanced technologies, participatory practices, and a deep commitment to worker well-being. This evolution is essential for creating industrial ecosystems that are not only efficient but also sustainable and resilient in the face of global challenges.

2. Integration of Advanced Technologies and Ergonomics

The integration of advanced technologies such as AI, cobots, and real-time data analytics is a defining feature of Industry 5.0, fundamentally transforming the practice of ergonomic design. Unlike traditional ergonomic interventions, which often relied on static assessments and manual adjustments, modern approaches leverage technology to create adaptive and responsive work environments. AI plays a central role in this transformation by enabling the continuous monitoring and optimization of workplace conditions.

One of the most significant advancements in this area is the use of wearable sensors and digital twins to collect real-time data on worker posture, movement, and physiological indicators. These technologies allow for the immediate identification of ergonomic risks, such as awkward postures or repetitive motions, and the implementation of corrective measures before they

result in injury or discomfort. Digital twins, in particular, provide a virtual representation of the workplace that can be used to simulate different scenarios and optimize ergonomic parameters without disrupting actual operations.

Collaborative robots, or cobots, are another key technological innovation in Industry 5.0. Designed to work in close proximity to humans, cobots can take on physically demanding or hazardous tasks, reducing the risk of injury and freeing workers to focus on more creative and value-added activities. The successful integration of cobots requires careful ergonomic planning to ensure that task allocation, workspace layout, and safety protocols are aligned with human capabilities and preferences. This often involves the use of multi-objective optimization algorithms that balance productivity, safety, and worker well-being.

AI-driven analytics further enhance the effectiveness of ergonomic interventions by providing actionable insights into worker performance and well-being. For example, AI can analyze data from wearable sensors to detect signs of fatigue or stress, prompting adjustments to work schedules or task assignments as needed. This proactive approach to ergonomics not only improves worker health but also contributes to higher levels of productivity and job satisfaction.

The integration of advanced technologies also facilitates the implementation of participatory design practices. Workers can provide feedback on their experiences and preferences through digital platforms, enabling continuous improvement of ergonomic solutions. This collaborative approach ensures that ergonomic interventions are tailored to the unique needs of each workforce, enhancing their effectiveness and sustainability.

Despite these benefits, the integration of advanced technologies into ergonomic design presents several challenges. These include the need for robust data security and privacy measures, the development of user-friendly interfaces, and the training of workers to effectively use new technologies. Addressing these challenges requires a multidisciplinary approach that combines expertise in ergonomics, engineering, data science, and organizational psychology.

Overall, the integration of advanced technologies and ergonomics in Industry 5.0 represents a significant step forward in the creation of human-centered workplaces. By leveraging AI, cobots, and real-time data analytics, organizations can create adaptive environments that prioritize worker health, safety, and productivity.

3. Enhancing Productivity through Human-Centered Ergonomics

One of the primary objectives of human-centered ergonomic design in Industry 5.0 is to enhance productivity without compromising worker well-being. The literature consistently demonstrates that ergonomic interventions, when properly implemented, lead to significant improvements in efficiency, quality, and output. This is achieved by optimizing the match between worker capabilities and job demands, minimizing physical and cognitive strain, and fostering a supportive work environment.

Ergonomic design contributes to productivity in several ways. First, it reduces the incidence of work-related injuries and illnesses, which are major sources of absenteeism and lost productivity. By designing workstations, tools, and processes that align with human anatomy and movement patterns, organizations can prevent musculoskeletal disorders and other health issues that disrupt operations. This not only benefits individual workers but also enhances overall organizational performance.

Second, ergonomic interventions improve task efficiency by streamlining workflows and reducing unnecessary movements or steps. For example, the use of adjustable workstations and tools allows workers to maintain optimal postures and minimize fatigue, enabling them to sustain high levels of performance throughout their shifts. The integration of cobots and AI-driven systems further enhances efficiency by automating repetitive or low-value tasks, allowing workers to focus on more complex and rewarding activities.

Third, human-centered ergonomics supports cognitive performance by reducing mental workload and decision fatigue. Intuitive interfaces, clear information displays, and adaptive automation systems help workers process information more effectively and make better decisions under pressure. This is particularly important in high-stakes environments where errors can have serious consequences for safety and productivity.

The literature also highlights the role of participatory design in enhancing productivity. When workers are involved in the design and implementation of ergonomic solutions, they are more likely to adopt new practices and technologies, leading to smoother transitions and higher levels of engagement. This collaborative approach fosters a culture of continuous improvement, where feedback is used to refine processes and address emerging challenges.

Moreover, the use of real-time monitoring and feedback systems enables organizations to identify and address productivity bottlenecks as they arise. By analyzing data on worker performance and well-being, managers can make informed decisions about task allocation, scheduling, and resource deployment, ensuring that productivity targets are met without overburdening employees.

However, the pursuit of productivity through ergonomic design must be balanced with a commitment to worker well-being. The literature cautions against the use of technology solely to increase output, as this can lead to unintended consequences such as increased stress or burnout. Instead, organizations are encouraged to adopt a holistic approach that considers the physical, cognitive, and psychosocial needs of workers.

In conclusion, human-centered ergonomic design is a powerful lever for enhancing productivity in Industry 5.0. By aligning work environments with human capabilities and leveraging advanced technologies, organizations can achieve sustainable gains in efficiency while supporting the health and satisfaction of their workforce.

4. CONCLUSION

Human-centered ergonomic design stands as a cornerstone of Industry 5.0, fundamentally reshaping industrial environments by integrating advanced technologies with a deep focus on worker safety, comfort, and fulfillment. By prioritizing ergonomics, Industry 5.0 not only optimizes human-machine collaboration but also creates adaptive, responsive, and inclusive workplaces that significantly reduce physical strain and cognitive overload, thereby enhancing both productivity and worker well-being. This approach empowers workers to engage in more meaningful, creative, and supervisory roles while leveraging automation to handle repetitive or hazardous tasks, resulting in improved job satisfaction, innovation, and organizational resilience. Ultimately, the adoption of human-centered ergonomic principles in Industry 5.0 ensures that technological progress serves to elevate human potential, fostering sustainable growth and a healthier, more motivated workforce.

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