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Synergizing Ergo-Technology by Integrating Physical, Cognitive, and Organizational Ergonomics for Sustainable Work System Design in Industry 4.0

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ABSTRACT

The manufacturing industry still relies heavily on manual labor to take advantage of human flexibility. As work-related injuries increase, the importance of ergonomics in engineering is becoming more recognized. However, in small and medium-scale manufacturing, the application of ergonomics has not yet received sufficient attention. The aim of this study is to review literature on the application of ergonomics in work system design, identify common approaches, analyze the impact of ergonomics, and provide recommendations for more effective implementation. A descriptive qualitative approach with a literature review of Google Scholar-indexed articles was used. The analysis concludes that ergonomics application in manufacturing is growing, with a predominant use of quantitative methods. Additionally, integrating physical, cognitive, and organizational ergonomics has positively impacted innovation and job satisfaction. Based on these findings, future research should focus on developing integrated ergonomic interventions, long-term studies, and economic analyses to improve ergonomics implementation.
Keyword: Physical Ergonomics, Cognitive Ergonomics, Organizational Ergonomics, Manufacturing Industry, Sustainable Work System

ABSTRAK

Industri manufaktur masih sangat bergantung pada tenaga kerja manual guna memanfaatkan fleksibilitas manusia. Seiring meningkatnya kasus cedera kerja, pentingnya studi ergonomi semakin diakui dalam bidang rekayasa. Namun, pada sektor manufaktur skala kecil dan menengah, penerapan ergonomi belum menjadi perhatian utama. Penelitian ini bertujuan untuk meninjau tren literatur yang membahas penerapan ergonomi dalam perancangan sistem kerja di industri manufaktur, mengidentifikasi pendekatan yang banyak digunakan, menganalisis dampak penerapan ergonomi serta merumuskan rekomendasi untuk penerapan ergonomi yang lebih efektif. Pendekatan kualitatif deskriptif dengan metode literatur review dari artikel jurnal terindeks Google Scholar digunakan dalam penelitian ini. Berdasarkan analisis tersebut, disimpulkan bahwa penerapan ergonomi dalam industri manufaktur sudah semakin berkembang, pendekatan yang mengkaji bidang ini pun didominasi menggunakan metode kuantitatif, selain itu, integrasi dari ergonomi fisik, kognitif, dan organisasi terbukti memiliki dampak positif terhadap inovasi dan kepuasan kerja. Berdasarkan hal tersebut, rekomendasi penelitian selanjutnya mengusulkan fokus pada pengembangan intervensi ergonomi terintegrasi, studi jangka panjang, dan analisis ekonomi.
Keyword: Ergonomi Fisik, Ergonomi Kognitif, Ergonomi Organisasi, Industri Manufaktur, Sistem Kerja Berkelanjutan

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1. Introduction

The manufacturing industry involves a large portion of the workforce in assembly processes, as many stages are still performed manually to take advantage of human agility and flexibility [1], [2], [3], [4]. This process is essential to ensure that workplace design incorporates ergonomic principles, aiming to provide a safe and comfortable environment while improving productivity [5], [6], [7]. Productivity is a critical factor in the manufacturing industry [8], [9]. To enhance work productivity, industries need to ergonomically design their work systems by considering both human and environmental factors within the production system [10], [11]. Human factors, work culture, and environmental conditions have a significant impact on work productivity [12], [13].

The field of engineering has increasingly emphasized the importance of ergonomic studies, in response to the rising number of reported workplace injuries [14], [15]. In highly industrialized and competitive countries, industries must preserve their human resources by prioritizing occupational health and safety [16]. Work-related injuries caused by poor manual lifting techniques remain a serious issue, even in highly developed nations [17].

In general, the application of ergonomics aims to develop and implement techniques that align work with human capabilities, identify safe and effective methods, and optimize worker well-being to improve productivity [18], [19]. In the context of ergonomics, there are three essential elements—human factors, technical factors, and environmental factors—all of which are inseparable [20], [21]. These three elements interact to form an integrated work system, not only by adapting humans to machines and the work environment, but also by modifying technical and environmental aspects to be more human-centered [22], [23]. The design of machines, equipment, workspace layout, and environmental conditions—such as lighting, temperature, and noise—should be based on human needs and comfort [24], [25].

According to data from the International Labour Organization (ILO), more than 2.3 million people die annually due to occupational accidents and work-related illnesses, with the majority of cases occurring in the manufacturing and construction sectors [26]. In Indonesia, the Social Security Administration for Employment (BPJS Ketenagakerjaan) reports over 200,000 occupational accident cases each year, most of which are caused by non-ergonomic working postures and suboptimal workplace conditions [27]. The high incidence of workplace accidents highlights the critical importance of applying ergonomic principles in work systems. This aligns with holistic ergonomics theory, participatory ergonomics theory, and the domino theory of workplace accidents, all of which emphasize the central role of humans within an integrated work system, aiming to create a safe, healthy, and productive work environment [28], [29], [30].

However, there remains a noticeable disconnect between ergonomic concepts and their real-world application, particularly in small and medium-sized manufacturing enterprises (SMEs), where ergonomics is often not treated as a priority. This situation highlights the need for a comprehensive review of how ergonomics has been implemented in work system design, the methods employed, and the extent to which these efforts contribute to enhancing work performance and employee well-being.

Therefore, the aim of this study is reviewing the literature on the application of ergonomics in the design of work systems within the manufacturing industry, identify the most commonly used approaches, analyze the impacts of ergonomic implementation by classifying findings from previous studies, and formulate evidence-based recommendations for more effective ergonomic practices.

This study offers novelty through its specific approach to systematically mapping previous findings and integrating physical, cognitive, and organizational ergonomics into a single, comprehensive review framework. Few existing literature reviews have thoroughly combined these three aspects in the context of work systems in the manufacturing industry.

Through this review, it is expected that strategic recommendations can be provided for work system designers, industrial management, and policymakers to integrate ergonomics in a more structured and sustainable manner. The recommendations also aim to encourage future research that is more applicable and measurable, particularly within the context of manufacturing industries in developing countries. Accordingly, this study addresses the following research questions:

RQ1: What patterns can be observed in how ergonomics is applied to work system design within the manufacturing sector according to current literature?
RQ2: Which ergonomic techniques and approaches are most frequently utilized in designing work systems for manufacturing environments?
RQ3: How does the application of ergonomics influence productivity, workplace safety, and the overall well-being of employees in the manufacturing industry?

2. Research Method

The research adopts a descriptive qualitative design supported by a literature review of journal publications obtained through Google Scholar. By using this method, the researcher can explore existing studies in the relevant domain more thoroughly, which helps reveal various types of research gaps—ranging from limitations in empirical findings and theoretical frameworks to shortcomings in methods, practical applications, scopes of studied populations, and opportunities for future investigation. The data for this study were gathered through the Harzing's Publish or Perish application, with the following search parameters: keywords ("Physical ergonomics", "cognitive ergonomics", "organizational ergonomics", "work system", "productivity", "manufacturing industry", and "industry 4.0"), maximum results set to 1000, article type restricted to review articles only, and publication years limited to 2020–2025.

The initial search generated 999 documents. To streamline the review process, the results were refined using a citation-based sorting feature ("cites"), which reduced the pool to 138 papers. These documents were then checked through Mendeley by examining their titles, abstracts, and sources to remove duplicates and confirm compliance with the established inclusion standards. After this screening stage, only 43 articles met the requirements. This progressive reduction illustrates how applying more targeted selection criteria can sharpen the research scope and improve the relevance of the literature to the study's objectives.

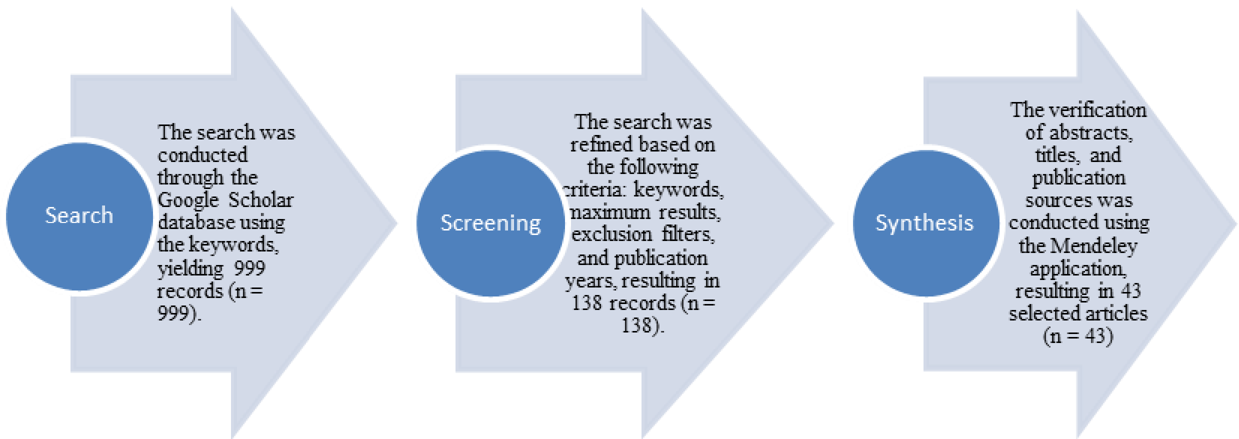

Figure 1. Research Method Flowchart

3. Result and Discussion

3.1. Paper Summary

A total of 43 selected articles deemed highly relevant to the research topic were systematically summarized. Each article was reviewed individually to obtain a deeper understanding of its content. A summary of the key aspects of each study is presented in Table 1.

Table 1. Overview of Relevant Literature

No.	Authors	Year	Method	Journal
1.	Zare, Nancy Black, Jean-Claude Sagot, et al. [31]	2020	Mixed Methods	International Journal of Industrial Ergonomics
2.	Ana Colim, Carlos Faria, Paula Carneiro, et al. [11]	2020	Quantitative	Applied science
3.	Virpi Kalakoski, et al. [32]	2020	Mixed Methods	Work
4.	Danang Trisusanto, Choirul Bariyah dan Agung Kristanto [33]	2020	Quantitative	Asia-Pacific Journal of Science and Technology
5.	Mohd. Iqbal, Iskandar Hasanuddin, Azmi Bin Hassan, et al. [34]	2020	Quantitative	International Journal of Integrated Engineering
6.	Rashid Heidarimoghadam, Hassan Khotanlou, Mohammad Babamiri, et al. [35]	2020	Quantitative	International Journal of Industrial Ergonomics
7.	Luca Gualtieri, Ilaria Palomba , Fabio Antonio Merati [36]	2020	Quantitative	Sustainability
8	Mildrend Montoya-Reyes, Margarita Gil-Samaniego-Ramos, Alvaro González-Angeles, et al. [37]	2020	Mixed Methods	Sustainability
9	Banibrata Das [38]	2021	Quantitative	International Journal of Industrial Ergonomics
10	Alireza Choobineh, Mahnaz Shakerian, Majid Faraji, et al. [39]	2021	Mixed Methods	International Journal of Industrial Ergonomics
11	Tiago Afonso, Anabela C. Alves, Paula Carneiro [40]	2021	Mixed Methods	International Journal of Global Business and Competitiveness
12	Ana Colim, Rita Morgado, Paula Carneiro, et al. [41]	2021	Mixed Methods	Sustainability
13	Daria Battini, Nicola Berti, Serena Finco, et al. [42]	2022	Quantitative	Computers & Industrial Engineering
14	Marianna Ciccarelli, Michele Germani, Alessandra Papetti, et al. [43]	2022	Mixed Methods	International Journal on Interactive Design and Manufacturing
15	Lukas Hausmanninger, Igor Komnik, Mario Fleiter, et al. [44]	2022	Quantitative	Human Factors and Ergonomics In Manufacturing
16	Michela Dalle Mura, Gino Dini [45]	2023	Quantitative	CIRP Journal of Manufacturing Science and Technology
17	Erni Suparti, Adhie Tri Wahyudi, Ana Fitrianingsih [46]	2023	Mixed Methods	Journal Opsi
18	Rahman Zare, et al. [47]	2024	Qualitative	A cell press Journal
19	Salmon P.M. Baber, Chris. Burns, Catherine, et al. [48]	2023	Qualitative	Human Factors and Ergonomics in Manufacturing
20	Riccardo Gervasi, Matteo Capponi, Luca Mastrogiacomo, et al. [49]	2023	Quantitative	The International Journal of Advanced Manufacturing Technology

No.	Authors	Year	Method	Journal
21	Marianna Ciccarelli, Matteo Forlini, Alessandra Papetti, et al. [50]	2024	Quantitative	The International Journal of Advanced Manufacturing Technology
22	Saahil Chand, Hao Zheng, Yuqian Lu. [51]	2024	Quantitative	Journal of Manufacturing Systems
23	Ali Keshvarparast, Nicola Berti, Saahil Chand, et al. [52]	2024	Quantitative	Computers & Industrial Engineering
24	Carlos Real dan Yaniel Torres [53]	2024	Quantitative	IEEE Access
25	Víctor Manuel Ramos-García, et al. [54]	2022	Quantitative	International Journal of Environmental Research and Public Health
26	Khadijah Sayyidatun Nisa, Abdussalam Topandi, Isma Wulansari, et al.	2024	Mixed Methods	Jurnal Inovasi Teknologi dan Rekayasa
27	Shemelis Nesibu Wodajeneh, Daniel Kitaw Azene, Eshetie Berhan, et al. [55]	2024	Quantitative	International journal of occupational safety and ergonomics
28	Violeta Firescu, et al. [56]	2024	Quantitative	International Journal on Industrial Engineering and Applications
29	Yord´ an Rodrıguez, et al. [57]	2024	Quantitative	WORK
30	I Ketut Gde Juli Suarbawa, M. Yusuf, Lilik Sudiajeng [58]	2024	Quantitative	International Journal On Advanced Science Enginerring Information Technology
31	Pablo Segura, et al. [59]	2024	Mixed Methods	Applied Sciences
32	Joseph Richards, David Golightly, Roberto Palacin [60]	2024	Quantitative	Applied Sciences, MDPI
33	Angeline Chepchirchir Kogo, Dr. Elizabeth Nambuswa Makokha [61]	2025	Quantitative	International Journal of Recent Research in Interdisciplinary Sciences (IJRRIS)
34	Isana Arum Primasari dan Tri Budiyanto [62]	2025	Mixed Methods	Journal of Engineering Design and Technology
35	Heri Setiawan, Sani Susanto, Micheline Rinamurti, et al. [63]	2025	Quantitative	Journal of Engineering Science
36	J. Dhande, P. Rane dan H. Dhande [64]	2025	Quantitative	International Journal of Industrial Engineering and Management
37	Stephen C. Nwanya dan Chidinma A. Ukohab [65]	2025	Mixed Method	International Journal of Occupational and Environmental Safety
38	Huizhong Cao, Francisco Garcia Rivera [66]	2025	Quantitative	Cognition, Technology & Work
39	Victor Bittencourt, Daniel Saakes, Sebastian Thiede [67]	2025	Quantitative	Journal of Manufacturing Systems

No.	Authors	Year	Method	Journal
40	Adailton G. Silva, Rafael Vieira Miguez, Lucas G. G. de Almeida, et al. [68]	2025	Qualitative	Applied Science, MDPI
41	Segura Pablo, Lobato-Calleros Odette, Soria Arguello Isidro, et al. [59]	2025	Quantitative	Applied Science, MDPI
42	A. Bonello, C.A Brownb, E. Francalanza, et al. [69]	2025	Mixed Method	Production & manufacturing research
43	Stephen C. Nwanya dan Chidinma A. Ukohab [65]	2025	Mixed Method	International Journal of Occupational and Environmental Safety

Based on the literature review summarized in the corresponding table, the application of ergonomics in the design of work systems within the manufacturing industry from 2020 to 2025 exhibits a trend toward increasingly systematic, measurable, and structured approaches. Technology has played an increasingly vital role in modern ergonomic practices[46]. Several studies highlight the use of digital simulation tools (e.g., Delmia V5, Arena), real-time platforms such as the WEM-Platform, IMU sensors, and automated monitoring systems[42]. These technologies enable real-time, rapid, and accurate ergonomic evaluations, particularly concerning posture, muscular load, and fatigue levels[44]. Such developments are aligned with the integration of ergonomics within the Industry 4.0 framework, where automation and data analytics underpin precise and informed decision-making[43], [45].

According to several studies, collaborative robots (cobots) in conjunction with lean manufacturing principles are increasingly utilized in workstation and work system redesigns[36]. The integration of ergonomics, lean principles, and robotics has been shown to reduce work time, lower physical strain, and enhance worker comfort[36]. Some interventions have demonstrated a reduction in standard time by up to 40% and an increase in productivity of up to 200%[35]. These findings suggest that ergonomic interventions not only improve occupational health but also directly influence operational outcomes[35].

Furthermore, successful ergonomic interventions heavily rely on collaboration among stakeholders, including workers, management, designers, and engineers[39]. Digital technologies and simulations support this process, offering objective and efficient evaluations through simulation software (e.g., Delmia, Arena), IMU sensors, and digital assessment tools[34]. This enables more accurate work system design and minimizes the need for trial-and-error in the field[34], [62].

Participatory strategies and ergonomic–lean–robotic integrations have also emerged as crucial factors. Participatory approaches engage workers from the early stages of problem identification through to solution development, ensuring that the resulting designs are relevant and broadly accepted[36]. The integration of lean and robotic technologies further underscores that ergonomics is not solely concerned with comfort but also with process efficiency and adaptability in the era of Industry 4.0[31]. When ergonomics is implemented holistically, work systems become more resilient, healthier, and better adapted to change[33].

In addition to physical aspects, several studies emphasize the importance of psychological and social ergonomic dimensions. Many analyses have examined perceptions of comfort, job satisfaction, and the relationship between ergonomics and innovation capacity[37]. Research employing Structural Equation Modeling (SEM) indicates that well-implemented ergonomic systems can improve worker health and foster innovation and creativity. These findings underscore the potential of ergonomics to enhance human resource quality while reducing fatigue-related risks[38].

The reviewed studies from 2020 to 2025 clearly demonstrate the growing importance of comprehensive ergonomic practices. The application of ergonomic principles and technology in manufacturing significantly contributes to improving productivity and work efficiency. Sensor-based monitoring systems and workstation modifications create safer, healthier, and more comfortable working environments, thereby reducing the risks of injury and fatigue[40].

In the manufacturing industry, posture assessment has emerged as the most commonly applied ergonomic approach in work system design[41]. Numerous studies have employed methods such as REBA, RULA, OWAS, and KIM-MHO to identify postures associated with musculoskeletal disorders (MSDs). These methods are favored for their practicality, ease of use in the field, and sufficient accuracy to support ergonomic intervention decisions[50].

Additionally, anthropometric approaches are the most prevalent in workstation redesign. Measurements of workers' body dimensions are used to adapt workstations, tools, and production equipment. Based on anthropometric data, these redesigns have been shown to enhance productivity and reduce ergonomic risks. This approach is widely used in workstation design studies due to its simplicity and effectiveness, as evidenced by reduced RULA scores and improved worker comfort[68].

A complementary strategy is the implementation of systemic framework visualization, which advocates for viewing ergonomics as an interconnected system rather than a procedural checklist[48]. This perspective helps system designers and policymakers understand that changes in one element (e.g., desk layout) can significantly impact other aspects (e.g., mental workload or team coordination). The systemic approach allows for more targeted and sustainable ergonomic interventions[49].

Participatory ergonomics, also referred to as the participatory approach, has gained traction in recent research. This method involves workers actively in identifying problems and proposing solutions, often through focus group discussions, interviews, and questionnaire surveys. As a result, the proposed solutions are more relevant and widely accepted. Additionally, such engagement raises worker awareness of ergonomics and enhances readiness for change[53].

Digital simulation has also become an integral part of modern ergonomic strategies. Simulation software such as Delmia V5 and Arena has been used in several studies to model virtual work systems, enabling researchers to evaluate multiple design scenarios without implementing physical changes in the workplace[51]. Tools like Design of Experiments (DOE) and Response Surface Methodology (RSM) are utilized to determine optimal ergonomic outcomes[52].

Technology-based methods such as electromyography (EMG), IMU sensors, and the WEM platform are increasingly adopted for real-time ergonomic assessments[42], [50]. These tools allow real-time evaluations of physical workload, muscle fatigue, and high-risk postures. Moreover, they provide direct feedback to workers, aiding them in correcting posture and minimizing ergonomic risk. These advances mark a significant shift toward data-driven and automated ergonomics[52].

Quantitative and statistical methods are essential for validating ergonomic outcomes. Most studies employed correlation analysis, regression models, and SEM to explore relationships between ergonomic risk factors and outcomes such as worker health, productivity, and innovation[58], [65]. These findings emphasize that ergonomics is no longer merely a technical issue but a strategic factor influencing overall organizational performance[65].

Integrated ergonomic approaches, often referred to as total ergonomics, are increasingly applied in the reviewed studies. These methods combine physical, cognitive, organizational, and environmental ergonomic assessments. Such multidimensional approaches yield more comprehensive and sustainable solutions.

This literature review confirms that ergonomics substantially enhances productivity in manufacturing. Most studies found that improved work efficiency reduces non-productive activities and extends production cycle time. For example, anthropometry-based workstation redesign has been shown to increase productivity by up to 200% and reduce standard working time by 40%[69]. The integration of digital simulation and lean manufacturing further enables the development of more efficient workstations, leading to significant reductions in idle time and production process optimization[69].

Ergonomics also contributes to improved occupational safety by mitigating the risk of musculoskeletal disorders (MSDs). Risky postures, heavy workloads, and repetitive movements are effectively identified using assessment tools such as REBA, RULA, NIOSH, and OWAS[70]. As a result of ergonomic interventions—such as introducing assistive devices, reorganizing workstations, and deploying collaborative robots—

ergonomic risk levels have been significantly reduced from high to moderate or low[70], [71]. Findings from studies conducted between 2024 and 2025 indicate that muscle complaints and fatigue levels decreased by more than 50%[71].

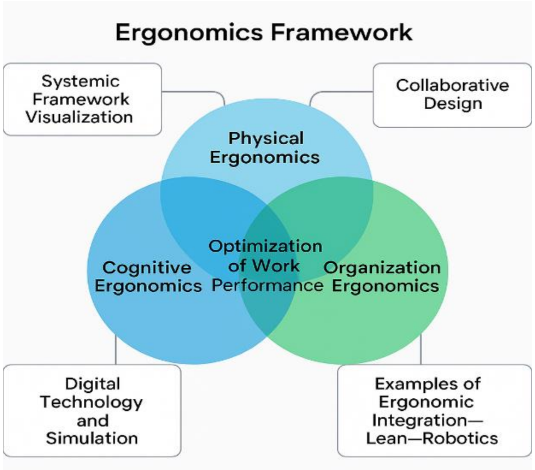

Figure 2. Ergonomics Framework

Furthermore, physical ergonomics focuses on aligning the work environment with the anatomical and physiological characteristics of workers[36]. This domain encompasses the design of equipment, assistive tools, and environmental conditions—such as temperature, lighting, and ergonomic working postures[69]. The primary objective is to minimize the risk of musculoskeletal disorders and fatigue resulting from repetitive movements or awkward postures, thereby enabling workers to perform their tasks efficiently and safely[63]. In practice, posture evaluation methods such as REBA, RULA, and the NIOSH lifting equation are employed to identify potential risks and to develop interventions that optimally support the physical well-being of workers[70].

On the other hand, cognitive ergonomics pertains to the mental processes involved as workers perceive, interpret, and respond to information within the work environment[72]. This dimension is essential for understanding how workers manage cognitive demands such as attention, working memory, decision-making, and situational awareness[54]. In the context of modern industrial settings, the design of information systems and human–machine interfaces must effectively support these cognitive processes to prevent mental fatigue, errors, and psychological strain[60]. Accordingly, cognitive ergonomics ensures that work systems are designed to optimally accommodate and enhance workers' mental capabilities[59].

In addition, organizational ergonomics focuses on the structures and cultural attributes within the workplace that influence team dynamics, communication patterns, and decision-making processes[67]. This domain encompasses the design of team structures, work schedules, and coordination and collaboration mechanisms both within and across departments[55]. Its primary objective is to establish a healthy and adaptive social system that fosters active participation and innovation among workers[56]. In the era of Industry 4.0, organizational ergonomics has become increasingly critical for ensuring a transparent work environment, fostering mutual trust, and cultivating a continuous learning culture capable of responding effectively to the challenges posed by automation and digitalization[47].

In a broader context, organizational ergonomics must adapt to dynamic work structures, decentralized workflows, and increasing human–system collaboration[67]. An effective organizational design ensures transparent communication, mutual trust, and balanced control within AI-driven work environments[64]. Consequently, the focus of Industry 4.0 extends beyond technological innovation to include ergonomic strategies that preserve and enhance human cognitive capabilities in the face of growing automation[57].

Subsequently, the integration of physical, cognitive, and organizational ergonomics becomes a fundamental cornerstone in designing sustainable and adaptive work systems in the era of Industry 4.0[47]. Physical ergonomics ensures that posture, biomechanical load, and workplace facilities are aligned with human physical capabilities[36]. Cognitive ergonomics addresses the increasing complexity of digital interfaces, information-processing demands, and the need for rapid decision-making that emerges with the adoption of intelligent technologies[72]. Meanwhile, organizational ergonomics aligns structures, roles, and communication flows to enable workers to adapt effectively to automation-based systems. Collectively, these three dimensions form the foundation for designing work systems that are both safe and efficient[57].

Moreover, within the context of Industry 4.0, the integration of these three ergonomic domains becomes increasingly critical as digitalization, the Internet of Things, cyber–physical systems, and human–robot collaboration reshape how humans work and interact with technology[43], [56]. Work system design must not only mitigate physical and cognitive risks but also ensure that organizational processes support flexibility, collaboration, and readiness for digital transitions[63]. Cognitive ergonomics reduces information overload, physical ergonomics maintains the feasibility of human–machine interaction, and organizational ergonomics ensures that work structures remain responsive and adaptive[66]. The synergy among these dimensions enables the creation of work systems that are sustainable, productive, and competitive in the Industry 4.0 era[46].

Looking ahead, future work systems must integrate principles of cognitive and organizational ergonomics within the framework of Industry 5.0, which emphasizes human-centered automation and efficiency[66], [73]. Cognitive ergonomics will play a critical role in the development of intelligent devices, decision-support mechanisms, and learning environments that align with human mental capacities[66]. Conversely, organizational ergonomics must cultivate socio-technical systems that promote continuous learning, psychological safety, and participatory innovation[73]. The synergistic integration of these two approaches facilitates the development of work systems that are efficient, meaningful, equitable, and environmentally responsible[32]. By positioning cognitive and organizational ergonomics as foundational elements of industrial transformation, modern workplaces can achieve a sustainable balance between technological advancement and human productivity enhancement[61], [66].

4. Conclusion

Based on the analysis, it can be concluded that the application of ergonomics in the manufacturing industry is increasingly evolving toward a more integrated, multidisciplinary, and technology-driven framework. Contemporary research now transcends the traditional view of ergonomics solely as a workplace health issue, recognizing it as a strategic approach to optimizing work systems that are not only efficient but also sustainable and conducive to workers' well-being. This paradigm shift paves the way for academics and industry professionals to develop adaptive ergonomic intervention models that effectively respond to the dynamic challenges posed by both current and future industrial landscapes.

The methods employed in numerous studies predominantly utilize quantitative approaches, such as the REBA, RULA, OWAS, and KIM-MHO, which consistently appear across a wide range of studies in the literature. This prevalence can be attributed to the practical advantages of quantitative methods in ergonomics research, particularly in the context of risk assessment, evaluating work environment quality, and conducting statistical analyses to explore the interrelationships between variables. These methods are especially favored for their ability to offer clear, measurable insights into ergonomic issues, thus facilitating more reliable data-driven decision-making.

Furthermore, optimizing work performance in modern industrial systems requires an integrated application of physical, cognitive, and organizational ergonomics. Physical ergonomics ensures safe and efficient bodily interaction with the work environment, while cognitive ergonomics supports the mental processes essential for effective decision-making and human–machine interaction. At the same time, organizational ergonomics fosters adaptive socio-technical structures that enhance collaboration, communication transparency, and participatory innovation. Within the context of Industry 4.0 and the emerging principles of Industry 5.0, the synergy among these ergonomic dimensions becomes increasingly critical for addressing the challenges posed by automation, digitalization, and decentralized workflows. Collectively, a comprehensive ergonomic approach not only improves productivity and safety but also promotes employee well-being, psychological resilience, and sustainable industrial transformation.

Based on the results and discussion, future research is expected to focus on the development of more integrated ergonomic interventions, long-term studies, and in-depth economic analyses of ergonomics to foster the creation of improved work environments.

Additionally, the limitations of this study include the lack of a comprehensive empirical analysis linking the integration of physical, cognitive, and organizational ergonomics with performance indicators such as productivity, well-being, and innovation in a quantitative manner. Therefore, further research employing a mixed-methods or experimental approach is necessary to test causal relationships and develop a more applicable integrated ergonomics framework.

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